NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

TELEDESIC'S CAPABILITIES TO MEET FUTURE DEPARTMENT OF DEFENSE WIDEBAND COMMUNICATIONS REQUIREMENTS

by

James O. Wickline

September 1998

Thesis Co-Advisors: Craig W. Baldwin
Donald v.Z. Wadsworth

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE September 1998	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE TELEDESIC'S CAPABILITIES TO MEET FUTURE DEPARTMENT OF DEFENSE WIDEBAND COMMUNICATIONS REQUIREMENTS	5. FUNDING NUMBERS
6. AUTHOR(S) Wickline, James, O.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release; distribution is unlimited.	

13. ABSTRACT *(maximum 200 words)* Success in modern military operations now depends upon the connectivity provided by communication systems. Space-based communication assets, due to their accessibility, coverage, flexibility, and global reach, are in many cases the only practical means to support transportable and mobile warfighter requirements. Joint Vision 2010's view of future warfighting and its higher, complex operational tempos will demand unprecedented distribution of information, for rapid warfighter interaction, battlefield coordination and joint interoperability. The increasing lethality, mobility and range of weapons, coupled with a smaller and more dispersed force structure, result in significantly increased amounts of three-dimensional battlespace over which an individual force element must maintain awareness and control. The end result is a lethal, deployable military, which is dependent on high-volume information transfers, most of which are graphical, pictorial, or data-intensive in nature. Information, and speed of delivery, are driving the warfighter's demand for higher capacity, wideband satellite communications systems. It is the focus of this research to assist DoD in ascertaining the correct, affordable mix of DoD owned SATCOM and commercial SATCOM that can best meet the warfighter's growing information requirements. The Teledesic Wideband Satellite Communication System is examined for future integration into the DoD MILSATCOM architecture and its military applications. Failure to provide the requisite amounts of communications to the right users when and where required will prevent a full return on the investment in advanced weapons, sensor platforms and combat support systems. Recognizing this, DOD needs to make an investment in Teledesic and other information age throughput technologies.

14. SUBJECT TERMS Teledesic, LEO, GEO, Naval communications, commercial wideband SATCOM, MILSATCOM	15. NUMBER OF PAGES 169
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298(Rev. 2-89)
Prescribed by ANSI Std. 239-18

Approved for public release; distribution is unlimited

TELEDESIC'S CAPABILITIES TO MEET FUTURE DEPARTMENT OF DEFENSE WIDEBAND COMMUNICATIONS REQUIREMENTS

James O. Wickline
Lieutenant Commander, United States Navy
B.A., History, University of Idaho, 1985

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SPACE SYSTEMS OPERATIONS

from the

NAVAL POSTGRADUATE SCHOOL
September 1998

Author: James O. Wickline

James O. Wickline

Approved by: Craig W. Baldwin

Craig W. Baldwin, Co-Advisor

Donald v. Z. Wadsworth

Donald v.Z. Wadsworth, Co-Advisor

R Panholzer

Rudolf Panholzer, Chairman
Space Systems Academic Group

ABSTRACT

Success in modern military operations now depends upon the connectivity provided by communication systems. Space-based communication assets, due to their accessibility, coverage, flexibility, and global reach, are in many cases the only practical means to support transportable and mobile warfighter requirements. Joint Vision 2010's view of future warfighting and its higher, complex operational tempos will demand unprecedented distribution of information, for rapid warfighter interaction, battlefield coordination and joint interoperability. The increasing lethality, mobility and range of weapons, coupled with a smaller and more dispersed force structure, result in significantly increased amounts of three-dimensional battlespace over which an individual force element must maintain awareness and control. The end result is a lethal, deployable military, which is dependent on high-volume information transfers, most of which are graphical, pictorial, or data-intensive in nature. Information, and speed of delivery, is driving the warfighter's demand for higher capacity, wideband satellite communications systems. It is the focus of this research to assist DoD in ascertaining the correct, affordable mix of DoD owned SATCOM and commercial SATCOM that can best meet the warfighter's growing information requirements. The Teledesic Wideband Satellite Communication System is examined for future integration into the DoD MILSATCOM architecture and its military applications. Failure to provide the requisite amounts of communications to the right users when and where required will prevent a full return on the investment in advanced weapons, sensor platforms and combat support systems. Recognizing this, DOD needs to make an investment in Teledesic and other information age throughput technologies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A. BACKGROUND

Success in modern military operations now depends heavily upon achieving information superiority and that superiority depends upon connectivity provided by communication systems. There is, therefore, a compelling need for highly capable communications assets to satisfy the growing information demands of the advanced warfighting and combat support systems in which the DoD is investing for today and the future.

Space-based communication assets, due to their accessibility, survivability, coverage, flexibility, and global reach, are in many cases the only practical means to support transportable and mobile warfighter and combat support platforms. Naval forces are globally deployed with beyond-the horizon separation of individual platforms as standard operating procedure. The Navy relies heavily on the use of satellite communications (SATCOM) for connectivity between platforms at sea because of an inability to use terrestrial-based systems and technologies such as fiber optics and microwave communications.

To understand the requirement for increased satellite communications connectivity, bandwidth and data rates, a

brief history of the use of SATCOM by DoD is necessary. Prior to the Gulf War with Iraq, 7th Fleet and other Fleet Commanders had issued directives that all surface units would use High Frequency (HF) communications while transiting their areas of operation. This was to maintain the Radiomen's proficiency with HF Communications in the event DoD satellites were destroyed during a time of War and to reduce message traffic on a limited asset. When war broke out in the Gulf this joint operation found different services competing for the use of communications satellites. It created an enormous message backlog and to make matters worse very few units used HF communications to pass their message traffic.

According to John Davis, Navy Space and Electronic Warfare Chief Scientist, operations were "rapidly exhausting the capacity we have" in FLTSATCOM UHF satellites. (Ref. 1: p. 36) One corrective measure included deployment of additional EHF ground segment, to make greater use of FLTSATCOM EHF transponders. Another initiative was installation of SHF DSCS terminals borrowed from the other services to supplement the small number of Navy WSC-6 terminals. It became clear that wideband communications were needed to supplement restrictive narrowband communications pipes. (Ref. 1: pp. 1,36)

Air Force Space Systems Division Commander Lt. Gen. Donald Cromer noted that existing satellite systems lack capacity to accommodate lower level commanders, and that the ground segment equipment is too large and expensive to permit use below the brigade level. He noted that for Army communications below Brigade, High-Frequency radio system are "unreliable for beyond-line-of-sight connectivity and they broadcast omni-directional, thus easily telling the enemy the transmitter location."(Ref. 2: p. 174)

The Iraqi force's use of SCUD missiles and the desire of US forces to eliminate the mobile launchers created the requirement for rapid imagery to help find and destroy the launchers before they could move. Another shortcoming documented during the conflict was the inability of legacy MILSATCOM systems to deliver large data and imagery files in a timely manner. These examples and others like them caused DoD to consider and evaluate the requirement for greater wideband communications with smaller mobile terminals. Increased SATCOM in the wideband spectrum would provide shared awareness, collaborative planning and synchronized action. Smaller terminals would give unit commanders a comprehensive view of the battlespace and allow direct feedback to upper echelon commanders.

Operation Joint Endeavor in Bosnia took lessons learned from Desert Storm but also offered it's own unique set of problems. A problem met in both Desert Storm and Operation Joint Endeavor was that the mobile tactical systems provided the users with only relatively thin pipes into close-to-saturated U.S. and NATO military communication satellite channels.

Bosnia presented a unique problem in its incredibly mountainous territory. This meant that line-of-sight communications were not practical or, in some cases not feasible, increasing the demand for use of communication satellites.

To fill this requirement the first operational Global Broadcast System (GBS) was deployed, dubbed by the Bosnian network the Joint Broadcast System (JBS). The JBS downlink hardware consisted of a commercial off-the-shelf receiver, able to handle compressed video, and a commercial off-the-shelf 1-meter dish. Leasing transponders on the Intelsat and the Orion satellite systems, obtained through the Commercial Satellite Communications Initiative (CSCI), provided Global Broadcast Service (GBS) to the theater. These transponders gave Joint Endeavor commanders the ability "to broadcast wideband data to a broad array of users. This will allow top commanders " to do operational planning and exchange high-

bandwidth data and imagery, such as plans, maps, charts and such." (Ref. 4: p. 2) JBS also allowed soldiers on the ground in Bosnia to watch real time video from a Predator UAV reconnaissance craft providing them with eyes in the sky they never had before. That live UAV feed, as well as other intelligence products, was also transmitted to the Pentagon to be analyzed for retransmittal to U.S. commanders over the JBS from an uplink located at the Naval Research Laboratory in Washington. (Ref. 3: pp. 4-6, Ref. 4: p. 2)

The multinational force of Joint Endeavor included forces from three nations: the United States, Great Britain and France. The ability to handle classified data among the allies was another key enhancement offered by the JBS operation. This was achieved by broadcasting intelligence information over two distinct networks: the Link Operations Intelligence Center-Europe (LOICE) and the Allied Command and Control Information System. The USS LaSalle used communication satellite circuits to exchange LOICE data, including imagery transfer and secure telephone capabilities, with multinational command headquarters in Zagreb as well as the U.S., British and French ground forces. Looking at the vast array of communications resources committed to the support of Joint Endeavor, DISA's Air Force Brig. Gen. James Beale, Defense Information

Systems Agency's (DISA), Director of Operations said, "This is more complex than Operation Desert Storm. We are learning lessons from the past." (Ref. 4: p. 2)

With accurate, timely and assured information, commanders and their staffs will be able to obtain and employ a superior knowledge and understanding of the battlespace in order to collaboratively formulate and disseminate plans and orders. They will be able to synchronize forces, exert effective control over the battlespace, sustain a high velocity of action and achieve dominance over the enemy through pre-emptive actions. Superior awareness allows a velocity of action and shortened timelines that knocks out an adversary's options and inflicts maximum losses upon him.

Joint Vision 2010's view of future warfighting and its higher, complex operational tempos will demand unprecedented distribution of information, rapid warfighter interaction and joint interoperability. The increasing lethality, mobility and range of weapons, coupled with a smaller and more dispersed force, result in significantly increased amounts of three-dimensional battlespace over which an individual force element must maintain awareness and control. The effectiveness of a warfighting force will increase as a function of that force's ability generate and

disseminate battlespace awareness. High-resolution sensors must be coupled directly with precision weapons to identify and take advantage of numerous target acquisition and engagement windows as well as provide immediate battle damage assessment (BDA). The required bandwidth and bit rates at which these requirements can be met is best suited for wideband satellite communications.

To meet the ever-increasing requirements for wideband communications DoD added Gapfillers to DSCS SLEP, GBS, and MILSTAR MDR. The Senior Warfighters' Forum's (Swarf) noted the gapfiller capability is short of the capacity needed to fully enable JV-2010. The Swarf reached the gapfiller decision with the expectation that, in the future, the commercial world would likely be in a position to provide much of the warfighters' capacity requirements. (Ref. 5: pp. 1-17 and 1-18)

Deployed forces will depend on information collected and stored around the world and available on-demand. Advanced, high resolution sensors, fewer but more precise weapons platforms, and planning/decision tools must quickly acquire, process, and fuse large amounts of information to be effective. Commanders at all echelons are embracing inter-network (web) technologies, video-teleconferencing, electronic meetings, and personal "on-the-go" communications

services as a means to more effectively exchange information, synchronize forces, and coordinate actions. Increased intelligence collection is compensating for reduced US overseas presence. High-resolution tactical and strategic intelligence and warning systems are having to sift through and produce tremendous amounts of information and data as they seek to improve their global, regional, and local vigilance in ever more challenging and complex environments. At the same time, field units are demanding more and more real and near-real time intelligence, warning, and battle damage data to support their continuously updated situation awareness. Training and planning for increasingly up-tempo military operations are leveraging realistic war-gaming simulations to analyze courses of action, rehearse missions, and train warfighters on their weapons systems. Data intensive combat support systems, integrated with "just in time" and "in-transit and total asset visibility" supply, service and transportation mechanisms, are reducing the amount of logistical forces and materiel that must be deployed. (Ref. 5: p. 1-6)

The end result is a fast acting, lethal, deployable, mobile, core military competency that has an ever-increasing dependence on high-volume information transfers, most of which are graphical, pictorial, or data-intensive in nature.

In addition to the increased volume of information, much of the information is highly perishable (delays in sensor-to-shooter targeting information - or lack of timely warning - can lead to missing the target - or being shot). The twin pressures of high-volumes of needed information, and the necessity to deliver information quickly, are driving the demand for higher capacity, wideband warfighter communications systems.

DoD faces the challenge of ascertaining the correct, affordable mix of DoD owned SATCOM and commercial SATCOM that can best meet the warfighter's growing information requirements. Simply buying more of today's DoD systems, such as DSCS, Milstar and UFO would be inadequate to meet the growing needs of future warfighters. Actions must be taken now to ensure adequate acquisition programs and appropriate plans for incorporating the use of commercial services are in place to meet these needs within the available budgets.

Failure to provide the requisite amounts of communications to the right users when and where required will prevent a full return on the investment in advanced weapons and sensor platforms and combat support systems. It is therefore imperative that information transfer capability not be a limiting factor in the effective application of US

combat power. Recognizing this, DOD needs to make major investments in information age technology.

It is therefore the goal of this thesis, to examine how emerging commercial wideband communication systems might supplement DoD communications system in the future. In particular, the planned Teledesic Wideband Communications system will be examined as to its suitability for use in military applications.

B. PURPOSE AND ORGANIZATION

This thesis examines the Teledesic Wideband Communications system currently being developed with its initial predicted operational capabilities and its potential military use. It will analyze the system with respect to acquisition strategies, cost, performance, coverage, availability, and vulnerability as they relate to projected DoD user requirements. The thesis is divided into six chapters. Chapter I provides the background, objective and organization of the thesis. Chapter II details specific DoD wideband communications requirements and their development process. Chapter III provides an overview of the Teledesic Wideband Communications system. Chapter IV develops military integration and applications for the Teledesic system. Chapter V provides an overview of military concerns,

suggests solutions and analyzes impacts on military applications. Chapter VI draws conclusions and makes recommendations based on the analysis conducted in previous chapters in order to determine to what extent developing commercial wideband communications systems could satisfy military requirements.

II. COMMERCIAL WIDEBAND SATELLITE COMMUNICATIONS REQUIREMENTS

A. REQUIREMENTS PROCESS

To understand the need for augmentation to DoD Wideband Communications Satellite Systems by commercial companies like Teledesic, it is important to understand how DoD wideband requirements are determined. Requirements generation is based upon a continuing process of assessing the capabilities of the current satellite communication systems to meet the projected threat, while taking into account opportunities for technological advancement, cost savings, and changes in national policy or doctrine. The process, known as mission area analysis (MAA) (or mission area assessment) will identify any deficiency, or a mismatch between current capabilities and the future (projected) threat. Once identified, deficiencies need to be resolved, and the first choice is a change in organization, doctrine or tactics, or perhaps additional training. These alternatives, often called non-material alternatives, are investigated first because of the relatively low cost and ease of implementation. Should non-material alternatives prove incapable of resolving the deficiency, we are forced to look for material solutions to satellite communication

requirement shortfalls (e.g., validated requirements that cannot be filled with apportioned assets). (Ref. 6: p. 21)

To identify satellite requirements a several step process has been generated. The first step is user requirement development using a standard method for stating requirements, followed by the requirement assessment process and requirements validation process. The Chairman of the Joint Chiefs of Staff (CJCS) prioritizes and approves requirements. The CJCS also manages the requirements program with Timely Feedback on the status of requirements submission. The central repositories of approved requirements are the Integrated Communications DataBase (ICDB) and the Emerging Requirements DataBase (ERDB). The assessment of user requirements supports the MILSATCOM architecture and formulates system requirements for acquisition.

1. Requirements Development

The CINCs are the advocates for their respective Area of Responsibility/Area of Operations (AOR/AOO). Each CINC will consolidate, validate, and prioritize all requests for use of MILSATCOM systems within the AOR/AOO. The CINCs conduct biennial deliberate planning for MILSATCOM. This review ensures that critical MILSATCOM requirements are current and adequately identified. The goal of this review

is to ensure that CJCS-approved Operational Plans (OPLANs), Contingency Plans (CONPLANs), and missions can be executed within apportioned and/or expected capacity. The CINCs will consolidate and prioritize all Military Satellite Communications (MILSATCOM) requirements (including requirements of components and supporting CINCs or Commands) that support validated OPLANs, CONPLANs, and assigned missions at all levels of conflict within their area of responsibility/area of operation. CINCs will forward a listing of prioritized requirements, including shortfalls that cannot be filled using apportioned assets, to the Joint Staff and provide an informational copy to USCINCSPACE. The listing of prioritized requirements is submitted not later than 1 February of even-numbered years. The results are used to revise deliberate planning guidance in the Joint Strategic Capabilities Plan (JSCP) and its Annex I, C3 systems. (Ref. 7: pp. 14, A-5)

The Services, Defense Agencies and United States Special Operations Command (USSOCOM) will validate and submit, through appropriate channels, Service and Special Operations Forces unique requirements for satellite system development and or testing, training, organizing, and equipping forces.

Services, Defense Agencies and USSOCOM will carefully review each requirement and associated performance characteristics and attributes identified to ensure each requirement is valid and has a clear operational concept. Each listed requirement should identify an associated OPLAN, OPORD, CONPLAN, and implementation directives, supported by these requirements and identify mission(s) supported. These reports also provide a mission impact if not satisfied. (Ref. 7: p. A-5)

2. Requirements Technical Assessment

DoD MILSATCOM requirements will be forwarded to the Joint SATCOM Panel Administrator (JSPA) for requirements processing. When a requirement is received by the JSPA, it is distributed to DISA as the Communications System Operations Manager (CSOM). DISA serves as the principal DoD SATCOM architect, to include development, preparation, and maintenance of a biennial architecture. The satellite architecture is supported by a DISA-developed acquisition roadmap for use by executive agents and a future requirements forecast that looks ahead 6, 10, and 20 years. (Ref. 7: p. 22)

DISA prepares a technical assessment describing alternative methods of achieving the communications request. This technical assessment endorses the requirement as

appropriate for satisfaction via a SATCOM system or identifies other media transmission paths. Technical assessments judge the potential for satisfying requirements on current or planned communications systems. It defines the capability of current or programmed communications (terrestrial or SATCOM) systems to satisfy the requirement. Requirements that cannot be satisfied by current or programmed systems or that will only be partially satisfied are identified as such. These requirements are input into the Emerging Requirements DataBase (ERDB) for future architectural planning. Technical assessments are forwarded to the JSPA for routine requirements or to the Joint Staff/CJCS for urgent requirements. (Ref. 7: p. A-8, Ref. 8: p. B-A-3)

USCINCSPACE and System Operational Managers provide assistance in the assessment of CINCs' MILSATCOM requirements as directed by DISA. The assesment supports the Integrated Space Architecture in DoD SATCOM architecture development. USCINCSPACE also serves as a principal advocate and advisor to the Chairman of the Joint Chiefs of Staff for MILSATCOM systems that support CINC operational requirements. (Ref. 7, pp. 19, 20)

The System Operational Managers (i.e. Naval Space Command and Airforce Space Command) develop facilities, as

appropriate, and procedures to allocate the system's communications capacity to satisfy validated operational requirements through all levels of conflict. They also provide technical and operational analysis of user requirements forwarded in preparation for review by the Joint SATCOM Panel. They conduct annual system assessments to determine the total satellite capacity available for allocation planning in each satellite coverage area. The results of the review are forwarded to the Chairman of the Joint Chiefs of Staff by 1 February each year for use in developing future MILSATCOM apportionment in the Joint SATCOM Panel. (Ref. 7: p. 20)

3. Requirements Approval

The Joint SATCOM Panel reviews MILSATCOM requirements with the associated assessments and makes a recommendation for approval or disapproval to the Chairman of the Joint Chiefs of Staff. The Joint Staff chairs the Joint MILSATCOM Panel comprised of representatives from each Service. The Joint Staff ensures that valid connectivity needs are also valid candidates for a SATCOM solution. Requirements are based on CJCS-approved missions and maintained in a single integrated database. The database indicates the degree to which requirements can be satisfied with current or programmed systems. The Joint Staff prioritizes requirements

to ensure satisfaction of the most critical needs and the effective and efficient use of resources. (Ref. 7: p. A-8, Ref. 8: p. B-A-4)

User representatives may attend panel meetings in support of requirements under consideration. Results of the panel meeting are incorporated into a joint action resulting in a final approval process for the requirements. The JSPA enters into the Integrated Communications Data Base (ICDB) all approved MILSATCOM requirements and provides timely notification to users stating whether requirements were approved or disapproved. Joint Staff/ CJCS initiates a review of all MILSTACOM requirements in the ICDB every 2 years. Results of the biennial MILSATCOM requirements update cycle are used by DISA as the primary source for updating the DoD SATCOM architecture. Interoperability and standardization among US forces and with allies is an essential consideration in MILSATCOM system planning, development, funding, and design. This interoperability focus is not only among SATCOM media capabilities but must also address the larger DoD C4 architectures. This is one of the reasons the Chairman of the Joint Chiefs of Staff has final approval of all SATCOM requirements. (Ref. 7: p. A-9, Ref. 8: p. B-A-4)

4. Satellite Communications Requirements DataBase

a) Integrated Communications DataBase

Defense Information Systems Agency (DISA) administers for the Chairman of the Joint Chiefs of Staff the ICDB of approved MILSTACOM requirements. The ICDB contains, but is not limited to, information necessary to support day-to-day operational management of all MILSATCOM systems: wartime deliberate planning: and future architecture preparation and system development. The ICDB design provides the capability to document requirements for connectivity regardless of whether the requirements can be satisfied on current or planned systems or a new future system.

The SATCOM architecture, developed by DISA, includes a SATCOM acquisition roadmap that identifies decision points, program and architecture options, SATCOM shortfalls, and key architecture issues based on the ICDB. The SATCOM architecture and roadmap are coordinated with the Chairman of the Joint Chiefs of Staff, the Services and CINCs. The approved architecture and roadmap are the basis for future systems Mission Needs Statements and Operational Requirements Documents and they provide guidance to system managers and lead Services for the Planning Programming and

Budgeting System (PPBS). (Ref. 7: p. A-13, Ref. 8: pp. B-A-1, B-A-2)

Mission Needs Statements and Operational Requirements Documents must be submitted to the Joint Requirements Oversight Council (JROC) for validation as required by DoD directive 5000.1 and DoD Instruction 5000.2 to support systems acquisition.

b) Emerging Requirements DataBase

DoD Services, CINCs and Agencies were surveyed by the Defense Information Systems Agency (DISA) to provide inputs describing their estimate of emerging MILSATCOM network requirements for the 2005-2010 time-frame and beyond. The requirements gathered in the survey are those not currently addressed in the existing MILSATCOM portions of the Joint Staff's Integrated Communications Database (ICDB: a comprehensive catalog of validated current and near-term network requirements that facilitates the management of existing communications systems). The ERDB is a database of projected future MILSATCOM network demands to be used in planning and sizing future MILSATCOM Architectures.

These estimates reflected the future warfighting doctrine and investment plans for advanced weapons, command

and control, and combat support systems and these systems' growing demands for information that should be satisfied by MILSATCOM. They derived their ERDB inputs from the information needs and operating concepts of their emerging systems platforms. The ERDB is a *unit-based* compilation of future SATCOM requirements. Using documents such as Joint Vision 2010 and "Out of the box thinking", the creation of the ERDB has provided a valuable planning tool intended to capture, as they become known, the Services', Defense Agencies and selected non-DoD activities' estimates of the MILSTACOM connectivity they may need 10-15 years out. (Ref. 9: p. 4)

The ERDB provides the foundation for the MILSATCOM capacity estimates and serves as an analytical basis on which to compare the relative performance of candidate future MILSATCOM architectures and systems proposals. The format for the ERDB was adapted from today's Integrated Communications Database (ICDB). The data base is maintained by the Defense Information Systems Agency (DISA) and is periodically reviewed and approved for planning purposes by the Joint SATCOM Panel (JSP). A mechanism will be put into place, as part of the JSP's ICDB update process, allowing the Unified Commands, Services, and defense Agencies to regularly update their ERDB entries. The ERDB was first

compiled in FY 95 and underwent a major update in FY 97. The ERDB entries are NOT validated requirements. The ERDB represents REQUEST FOR ALLOCATION in the out-years. (Ref. 5: p. 4-7, Ref. 8: p. B-B-1)

5. Future MILSATCOM Requirements

To emphasize the future requirements for SATCOM three scenarios were devised. These regional conflict scenarios lay down the users future needs expressed in the ICDB and the ERDB. They established an estimate, approved by the Joint Staff Joint SATCOM Panel for planning purposes, for the amounts of various types of MILSATCOM services US forces are projected to need in the 2010 timeframe. A top-level summary of the expected overall growth needed MILSATCOM capacity over time is shown in Figure 2-1.

Future MILSTACOM requirements resident in the ICDB and the ERDB were overlaid onto three representative (notional) operational scenarios adapted from the Defense Planning Guidance's scenario appendix and updated using US force strengths established in the 1997 QDR. The Three Scenarios employed are: (1) a peacetime employment scenario that models MILSATCOM user needs on a global basis under normal, day-to-day conditions (including forces in training or on routine patrol/duties); (2) a 2 MTW scenario in which US

forces have been deployed to two nearly simultaneous conflicts; and (3) a MSSC scenario in which US Forces have been deployed to four simultaneous conflicts/contingencies, each having force deployments lower in magnitude than those of the 2 MTW scenario. (Ref. 5: pp. 4-7, 4-8)

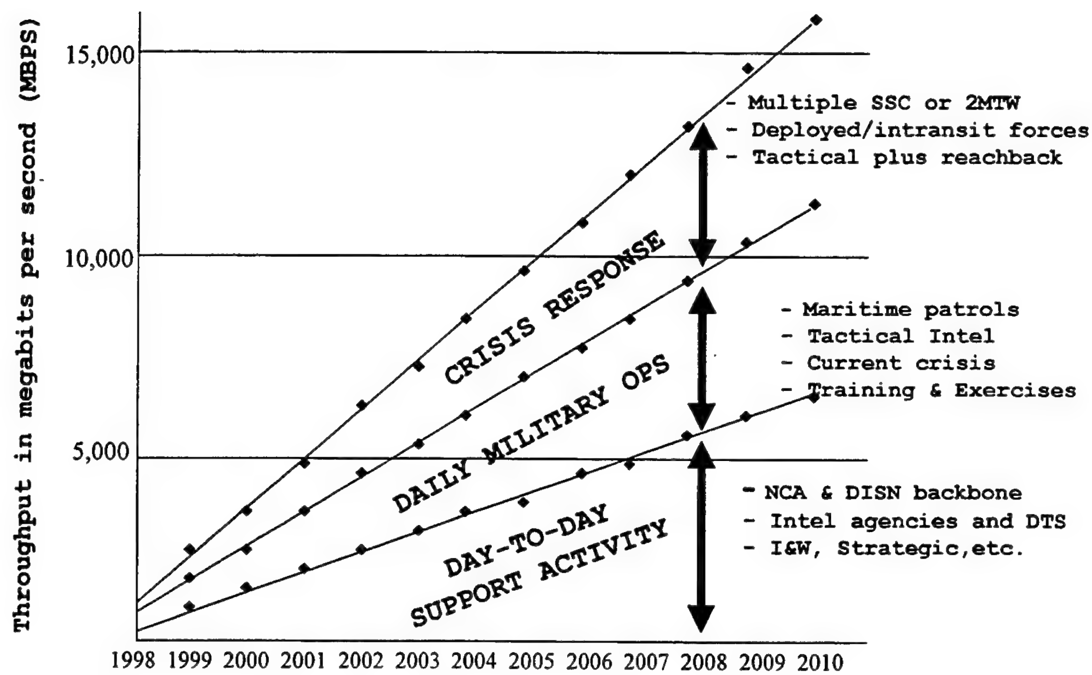

Figure 2-1, Predicted Growth in Required MILSATCOM Capacity. From Ref. [5].

The above figure emphasizes the need for DoD investment into future systems. According to RADM Dick Mayo (CNO N6), "the DoD has enough bandwidth to last until year 2002."

After 2002 the investments made in future military and commercial systems will be required to make up for shortfalls in bandwidth. As an example, the wideband requirements in the year 2010, for a single Carrier Battle Group in a major theater of war are estimated at 218,856 (kbps) which is almost half the current combined total DoD bandwidth. Because the acquisition cycle takes between five to ten years for any DoD system to come on line, the investment into those systems needs to be made now or the only hope for making up bandwidth shortfalls will be commercial communication systems. (Ref. 10, Ref. 11, Ref. 12: p. 18)

B. EXPANDING WIDEBAND REQUIREMENTS

As the overall requirement for communications increases so does the need for bandwidth. The military services and incorporation of ever-increasing number of complex technical weapons has created a dependence on wideband communications. The driver for this increased need for bandwidth comes from operational doctrines such as Joint Vision 2010 and the Navy's IT-21 initiative. The IT-21 vision anticipates creation of high capacity to/from many small terminals of 64kbs for each platform.

IT-21 envisions integration of Ground/Sea/Air sensors with duplex wideband communication. This will allow warfighters to conduct distributive collaborative planning, with video teleconferencing (VTC) among commanders. Under the Navy's IT-21 plan, a Naval Virtual Intranet would be created for future integration with the Defense Information System Network (DISN). (Ref. 13: pp. 5-9, 5-10)

Emerging Information Requirements are coming from force operational doctrines as well, such as "Maneuver from the Sea", which will entail amphibious assaults from over the horizon. There will be no intermediate staging areas and the bulk of the tactical forces will be beyond Line of Sight (LOS) of each other. The military wideband communications spectrum is anticipated to be available to create and maintain the tactical picture for the units making the assault. The Marine's future concept for operation "Sea Dragon", where small fire teams, geographically dispersed and beyond LOS or topographically constrained also will increase reliance on wideband SATCOM.

The concept of Fire Control Quality Data Exchange "CEC via SATCOM" (Co-operative Engagement Concept) is a large bandwidth driver. This concept provides integration of Ground/Sea/Air sensors. Another bandwidth driver is the Sensor Cueing Quality Data Exchange. This system provides

IR/ELINT/Acoustic Data Shared real-time via SATCOM to fuse disparate sensor inputs to support joint warfighting in all mission areas. Another driver of wideband service is the shortening of the decision cycle loop. This is often overlooked. The last is the concurrency of decision making requiring almost instantaneous information routing to several elements. (Ref. 14: pp. 82, 83)

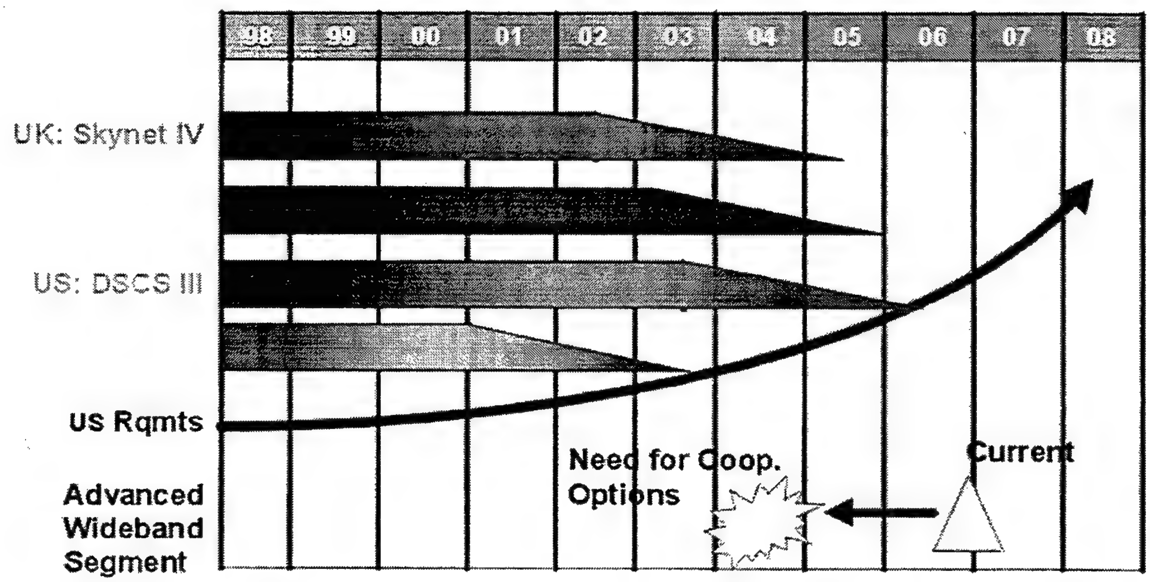

Figure 2-2, Exponential Increase for Bandwidth vs Wideband Systems End-Of-Life. From Ref. [15].

The advancement in current technical weapons systems and the emphasis on future systems has exponentially increased the demand for bandwidth (see Figure 2-2). The vision is to utilize wideband communications capable of performing mission updates for cruise missiles while or to

allow direct feed of video from UAVs to battlefield commanders for imagery transfer. The Navy expects to extend the Aegis capability overland and beyond the horizon in order to provide support joint warfighting with both TBMD and AAW enhancements.

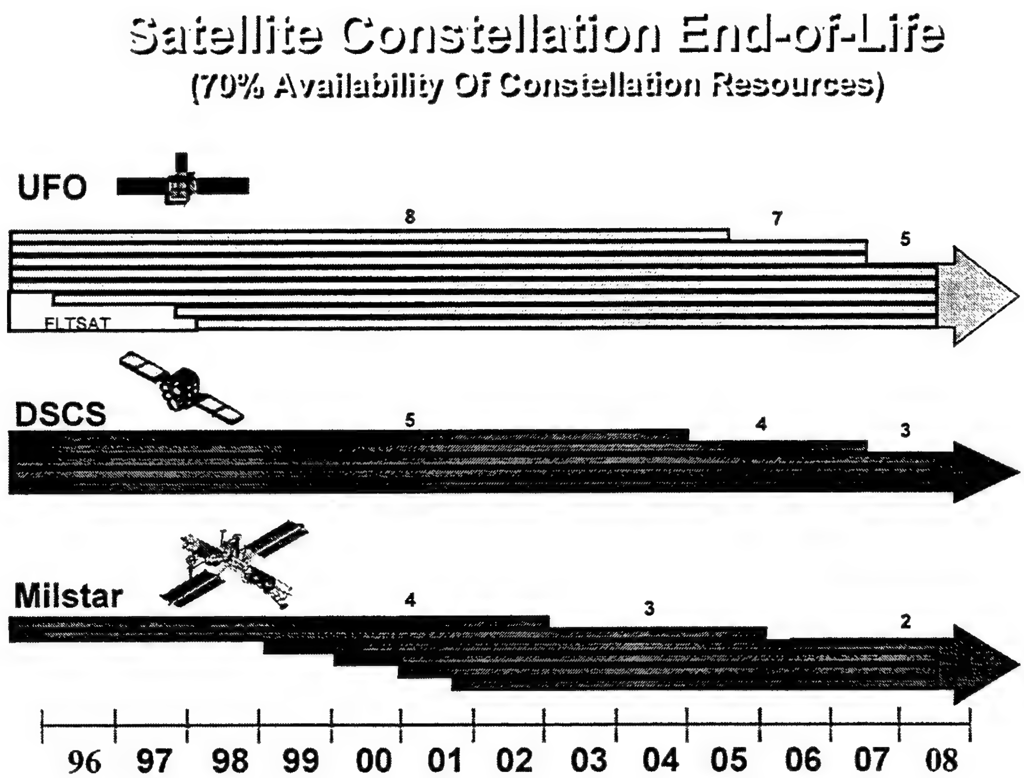

Figure 2-3, Satellite Constellation End-of-Life. From Ref. [15].

The fact that current satellite systems are nearing the end of their life expectancy, (see Figure 2-3) combined with the growth in DoD information and MILSATCOM requirements,

could seriously impede DoD's ability to fully realize the potential of future visions. Current MILSATCOM capabilities, DoD will be unable to effectively support the National Military Strategy of fighting two near-simultaneous MTWs in the 2003-2008 time frame. The DoD-owned legacy MILSATCOM capability is not expected to meet much of that timeframe's forecasted capacity needs. (Ref. 5: p. 3-1)

In late August 1996, the Joint Space Management Board (JSMB) approved in concept the Space Architect's long term "objectives, goals and strategy" for a future MILSATCOM architecture to meet the needed capacity. But they and the JROC remained concerned about the affordability of the requirements and costs of the underlying programs. In January 1997, the JROC set DoD's affordability goal for future owned and leased MILSATCOM systems. This goal is to spend, in the out-years, no more than DoD spends annually for satellite communications, as reflected in the 1998 President's Budget (which was already significantly reduced from Cold War levels). Accordingly, for the foreseeable future, DoD should expect no increases in the funding stream for satellite communications, and must face the possibility of further reductions. DoD will need to look to the commercial SATCOM market where spending is on the rise. (Ref. 5: pp. 1-14, 1-15)

Communication requirements to meet the goals of Joint Vision 2010 are expected to cost $60-65 billion over the next 20 years, yet only $40 billion is available in the President's budget to meet these requirements (Ref. 16: p. 9). The remaining dollars must come through fiscal initiative of the individual military services. A failure to fill this shortfall results in failure to meet the tactical needs of the next decade. One answer to fulfilling the needed bandwidth requirements of the future is to supplement DoD satellite wideband communication systems with commercial wideband satellite systems. (Ref. 16: p. 9)

C. COMMERCIAL REQUIREMENTS

The rapid pace of advancements in more capable and more affordable wideband commercial services and SATCOM technology is occurring independently of military need. Commercial space outspent DoD for the first time in 1996. This is considered a watershed in how the future of space monies will be spent, offering new, even revolutionary capabilities that can be exploited to meet the rapidly growing informational needs of warfighters and their rapidly growing informational needs. Commercial wideband satellite communications offer a reliable, cost effective opportunity to augment military satellite capabilities and personnel

quality-of-life while leveraging off rapid commercial technological advances and amortized cost structure. (Ref. 17: p. 6)

These new capabilities, combined with innovative acquisition and leasing strategies, have caused DoD to rethink how it acquires, uses and manages commercial resources. When militarily and economically feasible obviously it is advantageous to capitalize, on the commercial sector's existing and planned services, capabilities, and infrastructure. Many MILSTACOM requirements are, therefore, expected to be satisfied more economically by commercial means. Examples of current commercial SATCOM support to strategic and tactical mobile users include some broadcast services, personal communications service, and the use of commercial systems to enable information technology advancements in administrative and support functions (thereby allowing reduction in deployed manpower in these areas). Leasing commercial wideband services also may afford US Forces faster access to advanced capabilities and services than traditional government research, development and acquisition programs. (Ref 5: p. 1-11).

The advanced wideband services provided by Low Earth Orbit (LEO) systems such as Teledesic will provide increased

bandwidth at a time when DoD will need it the most without all the overhead associated with DoD owned and operated systems. It will provide flexibility for effective warfighter support and worldwide interoperability. The Teledesic wideband system will provide surge capacity and bandwidth not allocated via Defense Satellite Communications System (DSCS). Using a commercial wideband system to supplement military use also supports the congressional impetus to increase the use of commercial systems to fulfil requirements. (Ref. 18: p. 3)

III. OVERVIEW OF TELEDESIC WIDEBAND COMMUNICATIONS SYSTEM

A. TECHNICAL OVERVIEW OF THE TELEDESIC NETWORK

1. Introduction

Using a constellation of several hundred low-Earth-orbit satellites, Teledesic hopes to create an affordable access to fiber-like telecommunications services to institutions and individuals anywhere in the world. The Teledesic Network is a high-capacity wideband network that combines the global coverage and low latency of a low-Earth-orbit (LEO) constellation of satellites, the flexibility and robustness of the Internet, and "fiber-like" Quality of Service (QOS). Essentially an "Internet-in-the-Sky," the Teledesic Network brings affordable access to interactive wideband communication to all areas of the Earth, including those areas that could not be served economically by any other means.

The Teledesic Network can serve as the access link between a user and a gateway into a terrestrial network, or as the means to link users or networks together. Covering nearly 100 percent of the Earth's population and 95 percent of the landmass, the Teledesic Network is designed to support millions of simultaneous users.

2. Background

Teledesic was founded in 1990 and is headquartered in Kirkland, Washington. Principal shareholders are Craig O. McCaw and William H. Gates III. Mr. McCaw, who leads the company as its Chairman, is the founder of McCaw Cellular Communications, which he built into the world's largest wireless communications company before its 1994 merger with AT&T. Mr. Gates is the co-founder, Chairman and CEO of Microsoft Corporation, the world's largest computer software company. (Ref. 19: p. 1)

At the 1995 World Radio Conference, Teledesic received support to form a new international satellite service designation for the frequencies necessary to accommodate the Teledesic Network. The lowest frequency band with sufficient spectrum to meet Teledesic's wideband service, quality and capacity objectives is the Ka band. The terminal-satellite communication links operate within the portion of the Ka frequency band that has been identified internationally for non-geostationary fixed satellite service. Teledesic was also successful in obtaining a similar designation from the US Federal Communications Commission (FCC). In March 1997,

the FCC licensed Teledesic to build, launch, and operate the Teledesic Network. (Ref. 20)

On April 29,1997 Teledesic and Boeing announced that Boeing will become an equity partner in Teledesic and serve as the prime contractor for the company's global, broadband "Internet-in-the-sky." Boeing will invest up to $100 million for 10 percent of the current ownership of Teledesic. (Ref. 21: p. 1)

Teledesic's credibility was boosted by a new plan, presented by Boeing, to reduce the number of satellites in the network to 288 in a higher orbit than was projected in an original 824 satellite plan. The design also allows for additional satellites to be added to the system in groups of 12. Teledesic plans on drawing on the core competencies of Boeing, which include large-scale systems integration, software development and launch services.

On May 21,1998 Motorola invested roughly $750 million, replacing Boeing as the prime contractor, in the system in return for a 26% share in the system. While being replaced as the prime contractor, Boeing remains part of the development partnership of Teledesic. Motorola will be combining technical efforts already under way on the Teledesic system with those planned for the proposed Celestri system, which has now been abandoned and its

concepts merged into the Teledesic system. Teledesic also plans to draw on the partnership with Matra Marconi Space's expertise in satellite bus manufacturing. Teledesic and its partners hope to create a satellite network to provide, worldwide "fiber-like" access to telecommunications services such as broadband Internet access, videoconferencing and interactive multimedia. (Ref. 22: p. 1)

A test satellite for the Teledesic system was launched 26 February 1998. Dubbed the T1 it marks the first successful orbit of a commercial, Ka-band low earth orbit satellite. Teledesic plans to begin launching operational satellites in the year 2002 with service beginning the following year. Initially, Teledesic does not intend to market services directly to end-users. Rather, it will provide an open network for the delivery of such services by others. The Teledesic Network will enable local telephone companies and government authorities in host countries to extend their networks, both in terms of geographic area and in the kinds of services they can offer. Ground-based gateways will enable service providers to offer seamless links to other wireline and wireless networks. (Ref. 23: p. 1)

Teledesic's engineering effort builds on previous work done in many-advanced commercial and government satellite

programs and was assisted by several government laboratories. The Teledesic system utilizes proven technology and experience from many U.S. defense programs, such as the Strategic Defense Initiative (SDI) project "Brilliant Pebbles", which was conceived as a similar orbiting global constellation of 1,000 small, advanced, semi-autonomous, interconnected satellites. Since 1990, Teledesic has drawn on the expertise of the contractors on that and many other programs for input into the early system design activities. (Ref. 24, p. 5)

Design, construction, and deployment costs of the Teledesic Network are estimated at $9 billion. The Teledesic Network satellites and their associated subsystems will be designed and built in quantities large enough to be mass-produced and tested. In geostationary systems, any single satellite loss or failure is catastrophic to the system. To reduce this contingency to acceptable levels, reliability can be built into the network rather than the individual unit, reducing the complexity and cost of the individual satellites and enabling more streamlined, automated manufacturing processes and associated design enhancements. In its distributed architecture, dynamic routing, and scalability, the Teledesic Network emulates the Internet, while adding the benefits of real-time capability

and location-insensitive access.

3. System Overview

To ensure seamless compatibility with those networks, a satellite system must be designed with the same essential characteristics as fiber networks broadband channels, low error rates and low delays. Communications satellite systems are of two general types: geostationary-Earth-orbit (GEO) and non-geostationary, primarily low-Earth-orbit (LEO). Geostationary satellite systems orbit at an altitude of 22,300 miles (36,000 km) above the Equator, the only orbit that allows the satellite to maintain a fixed position in relation to Earth. At this height, communications through a GEO (which can travel only as fast as the speed of light) entail a round-trip transmission delay of at least one-half second. This GEO latency is the source of the annoying delay in many intercontinental phone calls, impeding understanding and distorting speech. What can be an inconvenience on voice transmissions, however, can be untenable for real-time applications such as videoconferencing as well as many standard data protocols. This means that GEOs can never provide fiber-like quality needed for some applications, especially the protocols of the Internet.

Geostationary satellite communications systems require changes to terrestrial network standards and protocols to accommodate their inherent high latency, the minimum half-second round-trip delay. Teledesic's objective is to meet current network standards rather than to change them. By using fiber-optics as the guideline for service quality, the Teledesic Network is designed for compatibility with applications that are based on today's and tomorrow's protocols. This places stringent requirements on the system design, including low latency, low error rates, high service availability, and flexible, broadband capacity - all characteristics of fiber. The advanced digital broadband networks will be packet-switched networks in which voice, video, and data are all just packets of digitized bits. It is not feasible to separate out applications that can tolerate delay from those that can't. As a result, the network has to be designed for the most demanding application. (Ref. 25: p. 1)

Teledesic plans to alleviate the known GEO communication problems with LEO orbits. Latency is a critical parameter of communication service quality, particularly for interactive communication and for many standard data protocols. To be compatible with the latency requirements of protocols developed for the terrestrial

broadband infrastructure, Teledesic satellites operate at a low altitude, under 435 miles (1,400 kilometers). Downlinks operate between 18.8 GHz and 19.3 GHz, and uplinks operate between 28.6 GHz and 29.1 GHz. Communication links at these frequencies are degraded by rain and blocked by obstacles in the line-of-sight. To avoid obstacles and limit the portion of the path exposed to rain requires that the satellite serving a terminal be at a high elevation angle above the horizon. The Teledesic constellation assures a minimum elevation angle (mask angle) of 40° above the horizon within its entire service area. (Ref. 26: p. 1)

The combination of a high mask angle and low-Earth orbit result in a relatively small satellite coverage zone, or footprint, that enables efficient spectrum re-use but requires a large number of satellites to serve the entire Earth. In the initial constellation, the Teledesic Network will consist of 288 operational satellites, divided into 12 planes, each with 24 satellites. (Ref. 26: p. 1)

Once the satellites are aloft they will circle in a polar orbit from north to south. Each will be linked electronically with eight neighbors in a geodesic pattern across the sky. As it moves out of range of a user, a satellite will hand off the radio signal to its nearest partner. A Teledesic user will rotate slowly eastward

beneath the constellation, passing under a new ring of satellites every hour or so. To pull in signals the user will use small antennas able to lock on to a moving satellite, and then flip back to pick up the next one as it comes into position. Today this type of operation is conducted by expensive kluge: the use of twin motorized antennas. The first antenna holds the signal while the second repositions itself. To make the antennas smaller and more versatile Teledesic plans to take advantage of advances in phased array technology to track a beam without moving the antenna physically. Phased array beam antennas will provide spatial and polarization separation of coverage areas. This, in combination with multiple access techniques, will allow Teledesic to reuse its frequencies thousands of times throughout the system.

The Teledesic Network consists of a ground segment (terminals, network gateways and network operations and control systems) and space segment (the satellite-based switched network that provides the communication links among terminals). Terminals are the hub of the Teledesic Network and provide the interface both between the satellite network and the terrestrial end-users and networks. They perform the translation between the Teledesic Network's internal protocols and the standard protocols of the terrestrial

world, thus isolating the satellite-based core network from complexity and change.

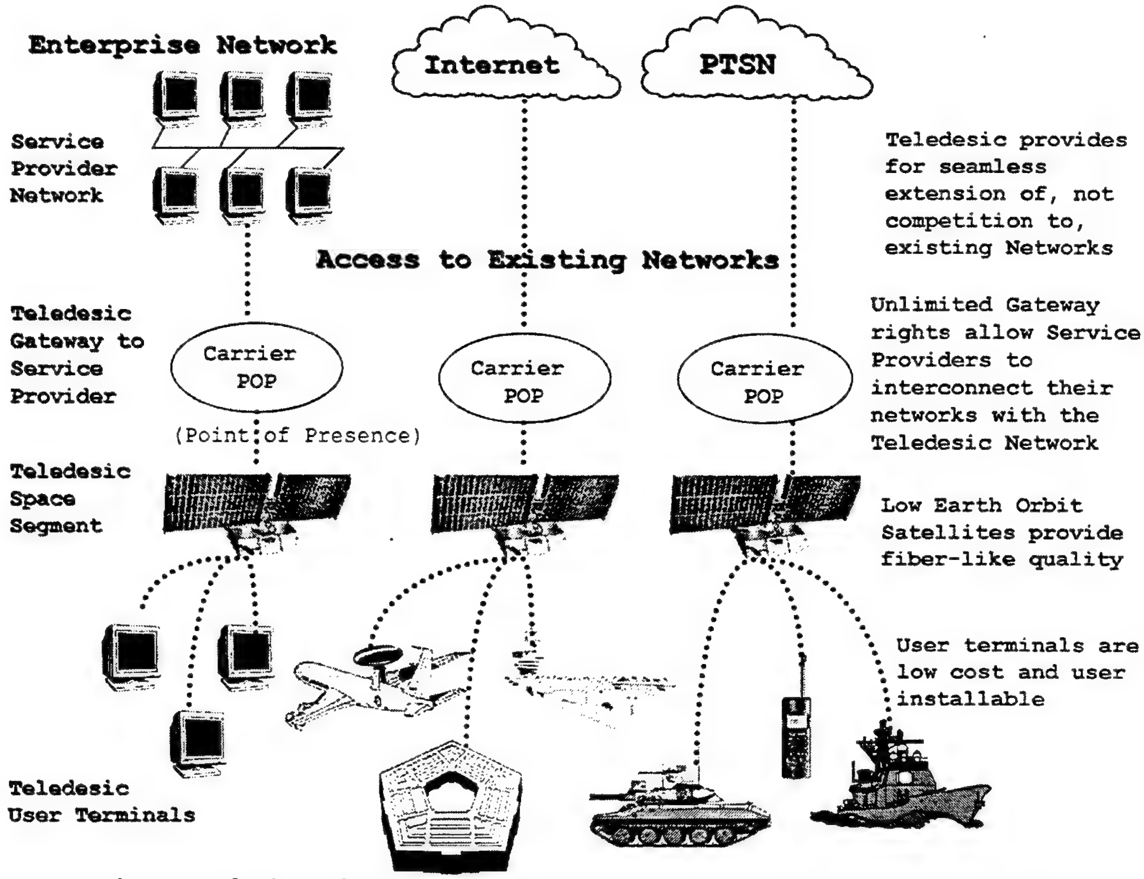

Figure 3-1, The Teledesic Network. After Ref. [26].

Teledesic terminals communicate directly with the satellite network and support a wide range of data rates. The terminals also interface with a wide range of standard network protocols, including IP, ISDN, ATM and others. Although optimized for service to fixed-site terminals, the Teledesic Network is able to serve transportable and mobile terminals, such as those for maritime and aviation

applications.

The ability to handle multiple channel rates, protocols and service priorities provides the flexibility to support a wide range of applications including the Internet, corporate Intranets, multimedia communication, LAN interconnect, wireless backhaul, etc. In fact, flexibility is a critical network feature, since many of the applications and protocols Teledesic will serve in the future have not yet been conceived.

4. Operational Capabilities

The Teledesic Network will provide a quality of service comparable to today's modern terrestrial communication systems, with bit error rates less than 10^{-9}, and a link availability of 99.9% over most of the United States. The 16 kbps basic channel rate supports low-delay voice coding that meets "network quality" standards.

The Network will offer high-capacity, "bandwidth-on-demand" through standard user terminals. Channel bandwidths range from a minimum of 16 kbps up to 2.048 Mbps ("E1") on the uplink, and up to 28 Mbps on the downlink. Teledesic also will be able to provide a smaller number of high-rate channels at 155 Mbps to 1.24416 Gbps ("OC-24") for gateway connections and users with special

applications. Most users will have two-way Wideband terminal connections that provide up to 64 Mbps on the downlink and up to 2 Mbps on the uplink. This represents access speeds up to 2,000 times faster than today's standard analog modems. The low orbit and high frequency (30 GHz uplink/20 GHz downlink) allow the use of small, low-power terminals and antennas, with a cost comparable to that of a notebook computer. (Ref. 20: p. 47)

Teledesic will use small, "earth-fixed" cells both for efficient spectrum utilization and to respect countries' territorial boundaries. Within a 53 by 53 km cell, the Network will be able to accommodate over 1,800 simultaneous 16 kbps voice channels, 14 simultaneous E1 (2.048 Mbps) channels, or any comparable combination of channel bandwidths. The Teledesic Network is designed to support a peak capacity of 1,000,000 full-duplex E1 connections, and a sustained capacity sufficient to support millions of simultaneous users. The Teledesic plans to scale up the Network to a much higher capacity by adding additional satellites.

The Teledesic terminals will provide the interconnection points for the Teledesic Network's Constellation Operations Control Centers (COCC) and Network Operations Control Centers (NOCC). COCCs coordinate initial

deployment of the satellites, replenishment of spares, fault diagnosis, repair, and de-orbiting. The NOCCs include a variety of distributed network administration and control functions including network databases, feature processors, network management and billing systems.

5. Satellite Design

The Teledesic satellites are complex, employing state-of-the-art technologies such as inter-satellite links, phased array antennas, advanced battery cells, and gallium arsenide integrated circuits. An underlying goal in their design is high volume production and test processes. On-orbit, the satellite will operate with a considerable degree of autonomy, with on-board systems for orbit determination, navigation, and health monitoring. Figure 3-2 illustrates the satellite's on-orbit configuration.

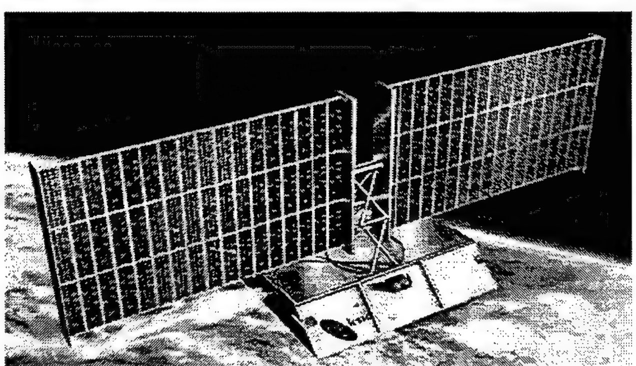

Figure 3-2, Teledesic Satellite in Orbit. From Ref. [26].

On-board processing will be accomplished through the command and data handling subsystem (C&DH), consisting of

multiple high-speed microprocessors, a high-capacity solid-state random access memory (RAM), a LAN for connection with other bus componets, as well as an engineering diagnostic and trending (EDAT) processor. The attitude and orbit determination and control (AODC) subsystem will use acquisition sun sensors to orient the satellite immediately after orbit insertion and inertial measuring units, magnetimeters, and precision microwave nadir-pointing information for attitude sensing afterward. Satellite attitude will be maintained in all three axes to within 0.2 degrees via magnetic torque and reaction wheels. The electronic beam steering of the antenna will have an accuracy of 0.1 degree. Stationkeeping and other orbit maneuvers will be performed using redundant low-thrust electric powered thrusters, which have a ΔV budget in excess of 1000 m/s. Thermal control will be semipassive using a combination of thermal blankets and paint for bus elements and phase-change and heat pipe devices for the payload. Batteries will allow full payload operation during eclipse periods. (Ref. 27: p. 3-8)

6. The Network

One or more local service providers in the United States and in each host country will serve end users. Terminals at gateway and user sites communicate directly with Teledesic's satellite-based network and through gateway switches, to terminals on other networks.

The network uses fast packet switching technology based on the Asynchronous Transfer Mode ("ATM") technology now being used in Local Area Networks ("LAN"), Wide Area Networks ("WAN"), and the Broadband Integrated Services Digital Network ("B-ISDN"). All communication is treated identically within the network as streams of short fixed-length packets. Each packet contains a header that includes destination address and sequence information, an error-control section used to verify the integrity of the header, and a payload section that carries the digitally-encoded user data (voice, video, data, etc.). Conversion to and from the packet format takes place in the terminals. The fast packet switch network combines the advantages of a circuit-switched network (low delay digital pipes), and a packet-switched network (efficient handling of multi-rate and bursty data). Fast packet switching technology is ideally suited for the dynamic nature of a LEO network.

(Ref. 26: p. 1)

Each satellite in the constellation is a node in the fast packet switch network, and has intersatellite communication links with eight adjacent satellites. Each satellite is normally linked with four satellites within the same plane (two in front and two behind) and with one in each of the two adjacent planes on both sides. This interconnection arrangement forms a non-hierarchical "geodesic," or mesh, network and provides a robust network configuration that is tolerant to faults and local congestion.

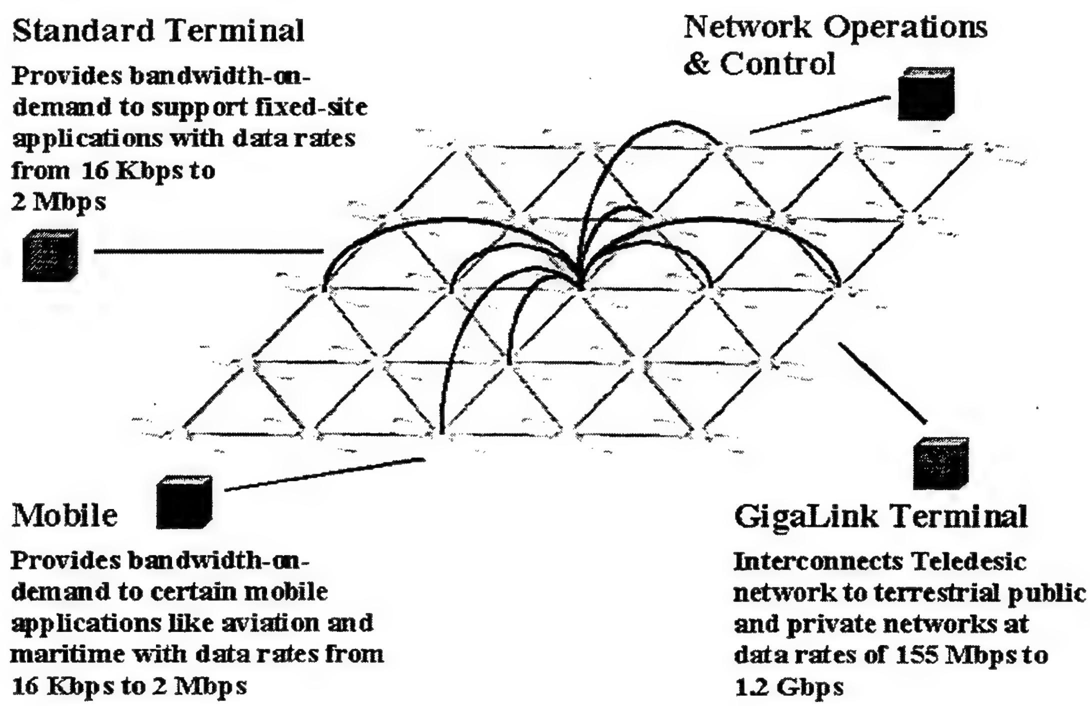

Figure 3-3, Teledesic Nodes. From Ref. [26].

The topology of a LEO-based network is dynamic. Each

satellite keeps the same position relative to other satellites in its orbital plane. Its position and propagation delay relative to earth terminals and to satellites in other planes change continuously and predictably. In addition to changes in network topology, as traffic flows through the network, queues of packets accumulate in the satellites, changing the waiting time before transmission to the next satellite. All of these factors affect the packet routing choice made by the fast packet switch in each satellite. These decisions are made continuously within each node using Teledesic's distributed adaptive routing algorithm. This algorithm uses information transmitted throughout the network by each satellite to "learn" the current status of the network in order to select the path of least delay to a packet's destination. The algorithm also controls the connection and disconnection of intersatellite links.

The network uses a "connectionless" protocol. Using a combination of destination-based packet addressing and a distributed, adaptive packet routing algorithm to achieve low delay and low delay variability across the network. Each packet carries the network address of the destination terminal, and each node independently selects the least-delay route to that destination. Packets of the same session

may follow different paths through the network (see Figure 3-4.). (Ref. 26: p. 1)

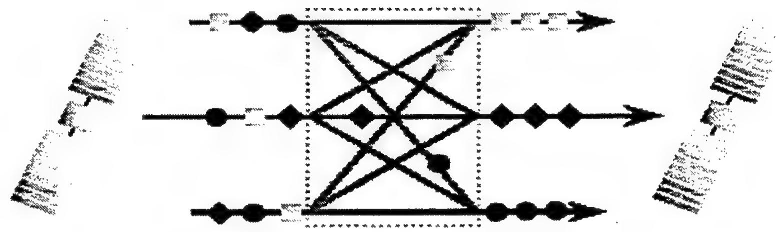

Figure 3-4, Teledesic's Distributed Adaptive Routing Algorithm. From Ref. [26].

Each node independently routes the packet along the path that currently offers the least expected delay to its destination. The required packets are buffered, and if necessary resequenced, at the destination terminal to eliminate the effect of timing variations. Teledesic has performed extensive and detailed simulation of the network and adaptive routing algorithm to verify that they meet Teledesic's network delay and delay variability requirements.

The richly interconnected mesh network is a robust, fault-tolerant design that automatically adapts to topology changes and to congested or faulty nodes and links. In essence, the system reliability is built into the constellation as a whole rather than being vulnerable to the failure of a single satellite. To achieve high system

capacity and channel density, each satellite is able to concentrate a large amount of capacity in its relatively small coverage area. Overlapping coverage areas plus the use of on-orbit spares permit the rapid repair of the network whenever a satellite failure results in a coverage gap. In essence, the system reliability is built into the constellation as a whole rather than being vulnerable to the failure of a single satellite. (Ref. 26: p. 1)

7. Communications Links and Terminals

All of the Teledesic communications links transport data and voice as fixed-length (512) bit packets. The basic unit of channel capacity is the "basic channel", which supports a 16 kbps payload data rate and an associated 2 kbps "D-channel" for signaling and control. Basic channels can be summed to support higher data rates. For example, eight basic channels can be summed to support the equivalent of a 2B + D ISDN link, or 97 channels can be summed to support an equivalent T1 (1.544 Mbps) connection. A Teledesic terminal can support multiple simultaneous network connections. In addition, the two directions of a network connection can operate at different rates.

The Teledesic Network accommodates a wide variety of terminals and data rates. Standard Terminals will include

both fixed-site and transportable configurations that operate at multiples of the 16 kbps basic channel payload rate up to 2.048 Mbps (the equivalent of 128 basic channels). These terminals can use antennas with diameters from 16 cm to 1.8 m as determined by the terminal's maximum transmit channel rate, climatic region, and availability requirements. Their average transmit power will vary from less than 0.01 W to 4.7 W depending on antenna diameter, transmit channel rate, and climatic conditions. All data rates, up to the full 2.048 Mbps, can be supported with an average transmit power of 0.3 W by suitable choice of antenna size. (Ref. 27: p. 3-22)

Within its service area, each satellite can support a combination of terminals with a total throughput equivalent to over 125,000 simultaneous basic channels. The Network also supports a smaller number of fixed-site GigaLink Terminals that operate at the OC-3 rate ("155.52 Mbps") and multiples of this rate up to OC-24 ("1.24416 Gbps"). Antennas for these terminals can range in size from 28 cm to 1.6 m as determined by the terminal's maximum channel rate, climatic region and availability requirements. Transmit power will range from 1 W to 49 W depending on antenna diameter, data rate, and climatic conditions. Antenna site-diversity can be used to reduce the probability of rain

outage in situations where this is a problem. (Ref. 27: p. 3-22)

The uplinks will use dynamic power control of the RF transmitters so that the minimum amount of power is used to carry out the desired communication. Minimum transmitter power is used for clear sky conditions. The transmitter power is increased to compensate for rain. The Teledesic FCC filings include link budgets for Standard, Mobile, and Gigalink terminals for both clear and heavy rain conditions. Heavy rain is defined as the rain rate at the 99.9 percentile for region D2 (temperate continental) using the Crane model. The objective bit error rate is given as 10^{-9} for all communication links. (Ref. 27: p. 3-25, Ref. 28: pp. 1717-1733)

For the Standard and Mobile Terminals, Teledesic intends to use shaped QPSK modulation with error correction coding. The required Eb/No given in their filing is 4.5 dB. The link budgets are based on a terminal uncoded uplink burst rate of 225 kb/s, which corresponds to a 16 kb/s user data rate. For higher user data rates a larger EIRP must be obtained using more amplifier power in combination with larger antennas. (Ref. 27: p. 3-25)

At Ka-band rain attenuation is a major factor in determining link margins. Teledesic attempts to reduce the

impact of rain by limiting the minimum terminal elevation angle to 40 degrees. The link budget for terminal elevation angles of 90 degrees is also provided. The Standard Terminal clear sky budget is shown in Table 3-1, and the heavy rain budget is presented in Table 3-2. The Mobile Terminal link budget is shown in Table 3-3 for the clear sky case, while that for heavy rain is shown in Table 3-4.

	40-Degree Elevation		**90-Degree Elevation**	
	Uplink	**Downlink**	**Uplink**	**Downlink**
Peak Transmit Power (Watts)	0.0126	75	0.0093	75
Transmit Antenna Peak Gain (dB)	36	32	36	29.8
Pointing Loss (dB)	-0.5	-2	-0.5	-2
EIRP	**16.5**	**48.8**	**15.2**	**46.6**
Frequency (GHz)	30	20	30	20
Slant Range (km)	1022	1022	700	700
Polarization Loss (dB)	0.5	0.5	0.5	0.5
Gaseous Loss (dB)	1.3	2.7	1	2.1
Rainfall Loss (dB)	0.0	0.0	0.0	0.0
Total transmission Loss (dB)	**184.0**	**181.9**	**180.4**	**178.0**
Receive Antenna Peak Gain (dB)	32	33	29.8	33
Pointing Loss (dB)	-2	-0.5	-2	-0.5
Antenna Loss (dB)	2	1	2	1
Receiver Noise Figure (dB)	3.5	2.5	3.5	2.5
G/T (dB/K)	**1.9**	**6.5**	**-0.3**	**6.8**
Uncoded Burst Data Rate (Mb/s)	0.225	324	0.225	324
Required Eb/No (dB)	4.5	4.5	4.5	4.5
Implementation Loss (dB)	2	2	2	2
Required C/No (dB-Hz)	**60.0**	**91.6**	**60.0**	**91.6**
Link Margin (dB)	3.0	10.4	3.0	12
Peak Flux density in 1 MHz (dBW/m^2)	-108.6	-106.4	-106.6	-105.3

Table 3-1, Standard Terminal Clear Sky Link Budget. From Ref. [20].

	40-Degree Elevation		90-Degree Elevation	
	Uplink	Downlink	Uplink	Downlink
Peak Transmit Power (Watts)	0.64	75	0.046	75
Transmit Antenna Peak Gain (dB)	36	32	36	29.8
Pointing Loss (dB)	-0.5	-2	-0.5	-2
EIRP	**33.6**	**48.8**	**22.1**	**46.6**
Frequency (GHz)	30	20	30	20
Slant Range (km)	1022	1022	700	700
Polarization Loss (dB)	0.5	0.5	0.5	0.5
Gaseous Loss (dB)	1.3	2.7	1	2.1
Rainfall Loss (dB)	19.0	9.0	9.0	4.0
Total transmission Loss (dB)	**203.0**	**190.9**	**189.4**	**182.0**
Receive Antenna Peak Gain (dB)	32	33	29.8	33
Pointing Loss (dB)	-2	-0.5	-2	-0.5
Antenna Loss (dB)	2	1	2	1
Receiver Noise Figure (dB)	3.5	2.5	3.5	2.5
G/T (dB/K)	**1.9**	**5.5**	**-0.3**	**6.8**
Uncoded Burst Data Rate (Mb/s)	0.225	324	0.225	324
Required Eb/No (dB)	4.5	4.5	4.5	4.5
Implementation Loss (dB)	2	2	2	2
Required C/No (dB-Hz)	**60.0**	**91.6**	**60.0**	**91.6**
Link Margin (dB)	1.0	0.4	1.0	7.4
Peak Flux density in 1 MHz (dBW/m^2)	-91.5	-106.4	-99.7	-105.3

Table 3-2, Standard Terminal Heavy Rain Link Budget. From Ref. [20].

	40-Degree Elevation		90-Degree Elevation	
	Uplink	**Downlink**	**Uplink**	**Downlink**
Peak Transmit Power (Watts)	0.051	75	0.037	75
Transmit Antenna Peak Gain (dB)	30	32	30	29.8
Pointing Loss (dB)	-0.5	-2	-0.5	-2
EIRP	**16.6**	**48.8**	**15.2**	**46.6**
Frequency (GHz)	30	20	30	20
Slant Range (km)	1022	1022	700	700
Polarization Loss (dB)	0.5	0.5	0.5	0.5
Gaseous Loss (dB)	1.3	2.7	1	2.1
Rainfall Loss (dB)	0.0	0.0	0.0	0.0
Total transmission Loss (dB)	**184.0**	**181.9**	**180.4**	**178.0**
Receive Antenna Peak Gain (dB)	32	27	29.8	27
Pointing Loss (dB)	-2	-0.5	-2	-0.5
Antenna Loss (dB)	2	1	2	1
Receiver Noise Figure (dB)	3.5	2.5	3.5	2.5
G/T (dB/K)	**1.9**	**0.5**	**-0.3**	**0.8**
Uncoded Burst Data Rate (Mb/s)	0.225	81	0.225	81
Required Eb/No (dB)	4.5	4.5	4.5	4.5
Implementation Loss (dB)	2	2	2	2
Required C/No (dB-Hz)	**60.0**	**85.6**	**60.0**	**85.6**
Link Margin (dB)	3.0	10.5	3.0	12.4
Peak Flux density in 1 MHz (dBW/m^2)	-108.5	-100.4	-106.6	-99.3

Table 3-3, Mobile Terminal Clear Sky Link Budget. From Ref. [20].

	40-Degree Elevation		90-Degree Elevation	
	Uplink	Downlink	Uplink	Downlink
Peak Transmit Power (Watts)	2.55	75	0.185	75
Transmit Antenna Peak Gain (dB)	30	32	30	29.8
Pointing Loss (dB)	-0.5	-2	-0.5	-2
EIRP	**33.6**	**48.8**	**22.2**	**46.6**
Frequency (GHz)	30	20	30	20
Slant Range (km)	1022	1022	700	700
Polarization Loss (dB)	0.5	0.5	0.5	0.5
Gaseous Loss (dB)	1.3	2.7	1	2.1
Rainfall Loss (dB)	19.0	9.0	9.0	4.0
Total transmission Loss (dB)	**203.0**	**190.9**	**189.4**	**182.0**
Receive Antenna Peak Gain (dB)	32	27	29.8	27
Pointing Loss (dB)	-2	-0.5	-2	-0.5
Antenna Loss (dB)	2	1	2	1
Receiver Noise Figure (dB)	3.5	2.5	3.5	2.5
G/T (dB/K)	**1.9**	**-0.5**	**-0.3**	**-0.1**
Uncoded Burst Data Rate (Mb/s)	0.225	81	0.225	81
Required Eb/No (dB)	4.5	4.5	4.5	4.5
Implementation Loss (dB)	2	2	2	2
Required C/No (dB-Hz)	**60.0**	**85.6**	**60.0**	**85.6**
Link Margin (dB)	1.0	0.4	1.0	7.4
Peak Flux density in 1 MHz (dBW/m^2)	-91.5	-100.4	-99.6	-99.3

Table 3-4, Mobile Terminal Heavy Rain Link Budget. From Ref. [20].

GigaLink Terminals provide gateway connections to public networks and to Teledesic support and data base systems including Network Operations and Control Centers ("NOCCs") and Constellation Operations Control Centers ("COCCs"), as well as to privately owned networks and high-rate terminals. A satellite can support up to sixteen GigaLink terminals within its service area. For Gigalink Terminals, 8-ary PSK modulation with error control coding is planned. The Eb/No requirement for these terminals is 10dB.

In this case Teledesic chose to use the maximum terminal uncoded burst rate in their calculations. Lower bit rate terminals will reduce their transmit power or antenna size accordingly. The budget for clear sky conditions is given in table 3-5, and the budget for rain conditions s provided in Table 3-6. (Ref. 27: p. 3-30)

	40-Degree Elevation		**90-Degree Elevation**	
	Uplink	**Downlink**	**Uplink**	**Downlink**
Peak Transmit Power (Watts)	0.96	0.72	0.42	0.28
Transmit Antenna Peak Gain (dB)	50	41	50	41
Pointing Loss (dB)	-0.5	-0.5	-0.5	-0.5
EIRP	**49.3**	**39.1**	**45.7**	**35.0**
Frequency (GHz)	30	20	30	20
Slant Range (km)	1022	1022	700	700
Polarization Loss (dB)	0.5	0.5	0.5	0.5
Gaseous Loss (dB)	1.3	2.7	1	2.1
Rainfall Loss (dB)	0.0	0.0	0.0	0.0
Total transmission Loss (dB)	**184.0**	**181.9**	**180.4**	**178.0**
Receive Antenna Peak Gain (dB)	41	47	41	47
Pointing Loss (dB)	-0.5	-0.5	-0.5	-0.5
Antenna Loss (dB)	2	1	2	1
Receiver Noise Figure (dB)	3.5	2.5	3.5	2.5
G/T (dB/K)	**12.4**	**20.5**	**12.4**	**20.8**
Uncoded Burst Data Rate (Mb/s)	1531	1531	1531	1531
Required Eb/No (dB)	10	10	10	10
Implementation Loss (dB)	2	2	2	2
Required C/No (dB-Hz)	**103.8**	**103.8**	**103.8**	**103.8**
Link Margin (dB)	2.5	2.5	2.4	2.5
Peak Flux density in 1 MHz (dBW/m^2)	-110.4	-120.6	-110.7	-121.5

Table 3-5, Gigalink Terminal Clear Sky Link Budget. From Ref. [20].

	40-Degree Elevation Uplink	Downlink	90-Degree Elevation Uplink	Downlink
Peak Transmit Power (Watts)	49	46	2.15	0.55
Transmit Antenna Peak Gain (dB)	50	41	50	41
Pointing Loss (dB)	-0.5	-0.5	-0.5	-0.5
EIRP	**66.4**	**47.1**	**52.8**	**37.9**
Frequency (GHz)	30	20	30	20
Slant Range (km)	1022	1022	700	700
Polarization Loss (dB)	0.5	0.5	0.5	0.5
Gaseous Loss (dB)	1.3	2.7	1	2.1
Rainfall Loss (dB)	0.0	0.0	0.0	0.0
Total transmission Loss (dB)	**203.0**	**190.9**	**189.4**	**182.0**
Receive Antenna Peak Gain (dB)	41	47	41	47
Pointing Loss (dB)	-0.5	-0.5	-0.5	-0.5
Antenna Loss (dB)	2	1	2	1
Receiver Noise Figure (dB)	3.5	2.5	3.5	2.5
G/T (dB/K)	**12.4**	**19.5**	**12.4**	**19.9**
Uncoded Burst Data Rate (Mb/s)	1531	1531	1531	1531
Required Eb/No (dB)	10	10	10	10
Implementation Loss (dB)	2	2	2	2
Required C/No (dB-Hz)	**103.8**	**103.8**	**103.8**	**103.8**
Link Margin (dB)	0.5	0.5	0.5	0.5
Peak Flux density in 1 MHz (dBW/m^2)	-93.3	-112.6	-103.6	-118.5

Table 3-6, Gigalink Terminal Heavy Rain Link Budget. From Ref. [20].

Intersatellite Links ("ISLs") interconnect a satellite with eight satellites in the same and adjacent planes. Each ISL operates at 155.52 Mbps, and multiples of this rate up to 1.24416 Gbps depending upon the instantaneous capacity requirement. The Inter-satellite link budget is presented in Table 3-7. Two conditions, nominal and when a receive antenna is facing into the sun, are considered. The maximum burst rate is used in the calculations. The Inter-satellite

links use 8-ary PSK modulation with error control coding. (Ref. 27: p. 3-30)

	Nominal		Into the Sun Elevation	
	Max. Range	**Min. Range**	**Max. Range**	**Min. Range**
Peak Transmit Power (Watts)	5.5	0.0082	5.5	0.0195
Transmit Antenna Peak Gain (dB)	48	48	48	48
Pointing Loss (dB)	-0.5	-0.5	-0.5	-0.5
EIRP	**54.9**	**26.6**	**54.9**	**30.4**
Frequency (GHz)	30	20	30	20
Slant Range (km)	2586	100	2586	100
Polarization Loss (dB)	0.5	0.5	0.5	0.5
Total transmission Loss (dB)	**198.6**	**168.9**	**196.8**	**168.5**
Receive Antenna Peak Gain (dB)	48	48	48	48
Pointing Loss (dB)	-0.5	-0.5	-0.5	-0.5
Antenna Loss (dB)	2	2	2	2
Receiver Noise Figure (dB)	4	4	4	4
G/T (dB/K)	**20**	**20.1**	**14.4**	**14.4**
Uncoded Burst Data Rate (Mb/s)	1531	1531	1531	1531
Required Eb/No (dB)	10	10	10	10
Implementation Loss (dB)	2	2	2	2
Required C/No (dB-Hz)	**103.8**	**103.8**	**103.8**	**103.8**
Link Margin (dB)	3.0	3.0	-2.7	1.0
Peak Flux density in 1 MHz (dBW/m^2)	-113.8	-113.9	-113.8	-110.1

Table 3-7, Inter-satellite Link Budget. From Ref. [20].

The links will be encrypted to guard against eavesdropping. Terminals perform the encryption/decryption and conversion to and from the packet format. The terminals perform uplink power control, but it is initiated by the satellite currently covering those terminals.

8. Earth-Fixed Cells

One benefit of a small satellite footprint is that each satellite can serve its entire coverage area with a number of high-gain scanning beams, each illuminating a single small cell at a time. Small cells allow efficient reuse of spectrum, high channel density, and low transmitter power. However, if this small cell pattern swept the Earth's surface at the velocity of the satellite (approximately 25,000 km per hour), a terminal would be served by the same cell for only a few seconds before a channel reassignment or "hand-off" to the next cell would be necessary. As in the case of terrestrial cellular systems, frequent hand-offs result in inefficient channel utilization, high processing costs, and lower system capacity. The Teledesic Network uses an Earth-fixed cell design to minimize the hand-off problem.

The Teledesic system maps the Earth's surface into a fixed grid of approximately 20,000 "supercells," each consisting of nine cells (see Figure 3-5). Each supercell is a square 160 km on each side. Supercells are arranged in bands parallel to the Equator. There are approximately 250 supercells in the band at the Equator, and the number per band decreases with increasing latitude. Since the number of

supercells per band is not constant, the "north-south" supercell borders in adjacent bands are not aligned. (Ref. 20: p. 48)

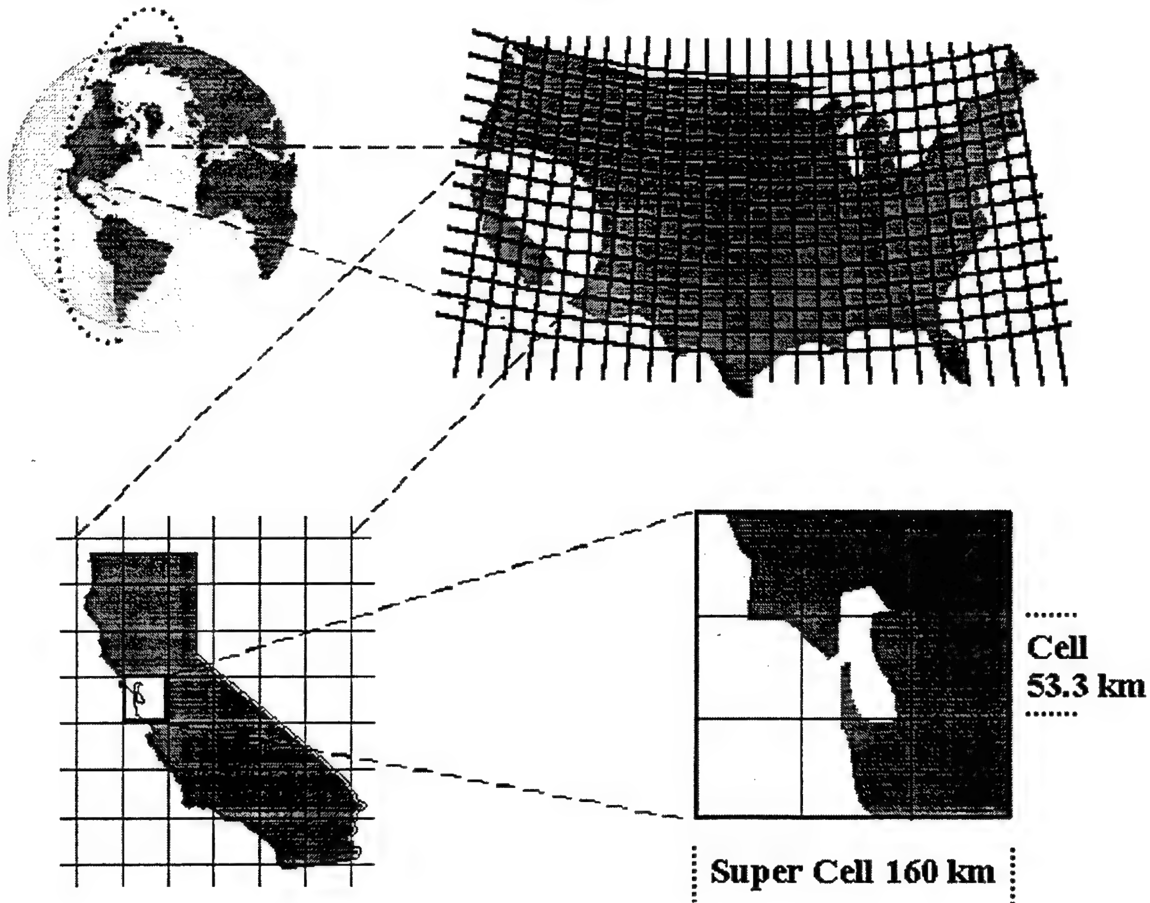

Figure 3-5, Teledesic's Earth-Fixed Cells. From Ref. [20].

A satellite footprint encompasses a maximum of 64 supercells, or 576 cells. The actual number of cells for which a satellite is responsible varies by satellite with its orbital position and its distance from adjacent satellites. In general, the satellite closest to the center of a supercell has coverage responsibility. As a satellite

passes over, it steers its antenna beams to the fixed cell locations within its footprint. This beam steering compensates for the satellite's motion as well as the Earth`s rotation. This concept is illustrated in Figure 3-6.(Ref.20:p.49)

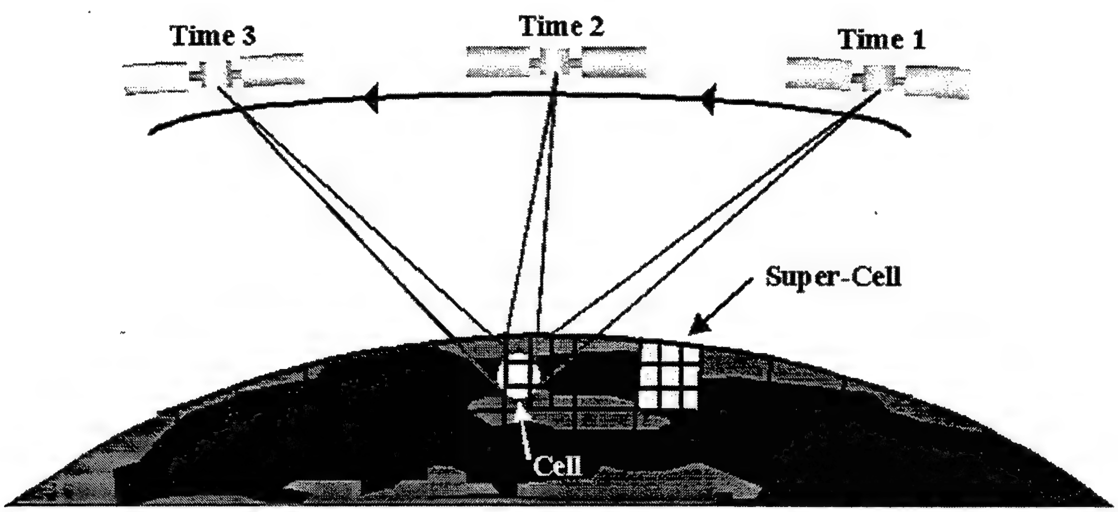

Figure 3-6, Illustration of Beam Steering to an Earth-Fixed Cell. From Ref. [20].

Channel resources (frequencies and time slots) are associated with each cell and are managed by the current "serving" satellite. As long as a terminal remains within the same Earth-fixed cell, it maintains the same channel assignment for the duration of a call, regardless of how many satellites and beams are involved. Channel reassignments become the exception rather than the normal case, thus eliminating much of the frequency management and hand-off overhead.

A database contained in each satellite defines the type of service allowed within each Earth-fixed cell. Small fixed cells allow Teledesic to avoid interference to or from specific geographic areas and to contour service areas to national boundaries. This would be difficult to accomplish with large cells or cells that move with the satellite.

9. Multiple Access Methods

The Teledesic Network uses a combination of multiple access methods to ensure efficient use of the spectrum. Each cell within a supercell is assigned to one of nine equal time slots. All communication takes place between the satellite and the terminals in that cell during its assigned time slot (see Figure 3-7). Within each cell's time slot, the full frequency allocation is available to support communication channels. The cells are scanned in a regular cycle by the satellite's transmit and receive beams, resulting in time division multiple access ("TDMA") among the cells in a supercell. Since propagation delay varies with path length, satellite transmissions are timed to ensure that cell N (N=1, 2, 3,...9) of all supercells receive transmissions at the same time. Terminal transmissions to a satellite are also timed to ensure that transmissions from the same numbered cell in all supercells

in its coverage area reach that satellite at the same time. Physical separation (space division multiple access or SDMA) and a checkerboard pattern of left and right circular polarization eliminate interference between cells scanned at the same time in adjacent supercells. Guard time intervals eliminate overlap between signals received from time-consecutive cells. (Ref. 20: pp. 50,51)

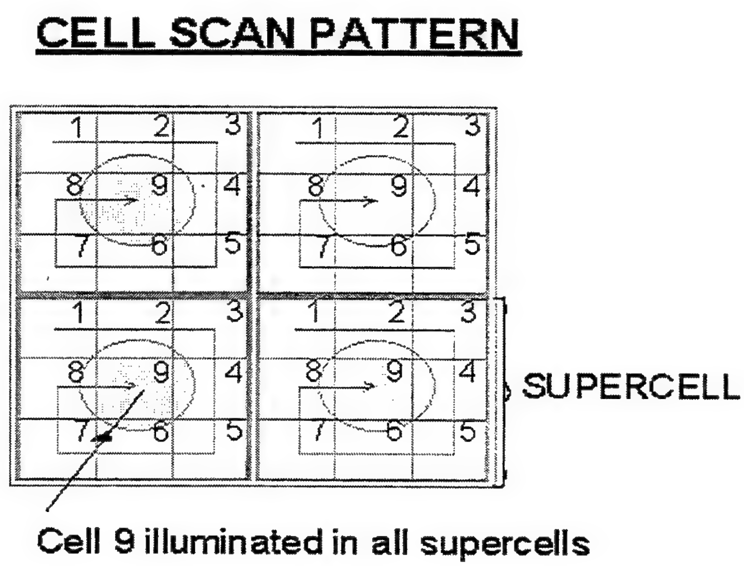

Figure 3-7, Teledesic's Cell Scan Pattern. From Ref. [20].

A multiple access scheme implemented within the terminals and the satellite serving the cell manages the sharing of channel resources among terminals. Within a cell, channel sharing is accomplished with a combination of Multi-Frequency Time Division Multiple Access (MF-TDMA) on the

uplink and Asynchronous Time Division Multiplexing Access (ATDMA) on the downlink.

On the uplink, each active terminal is assigned one or more frequency slots for the call's duration and can send one packet per slot each scan period (23.111 msec). The number of slots assigned to a terminal determines its maximum available transmission rate. One slot corresponds to a Standard Terminal's 16 kbps basic channel with its associated 2 kbps signaling and control channel. A total of 1800 slots per cell scan interval are available for Standard Terminals (see Figure 3-8). (Ref. 20: p.51, Ref. 29, Ref. 27: p. 3-23)

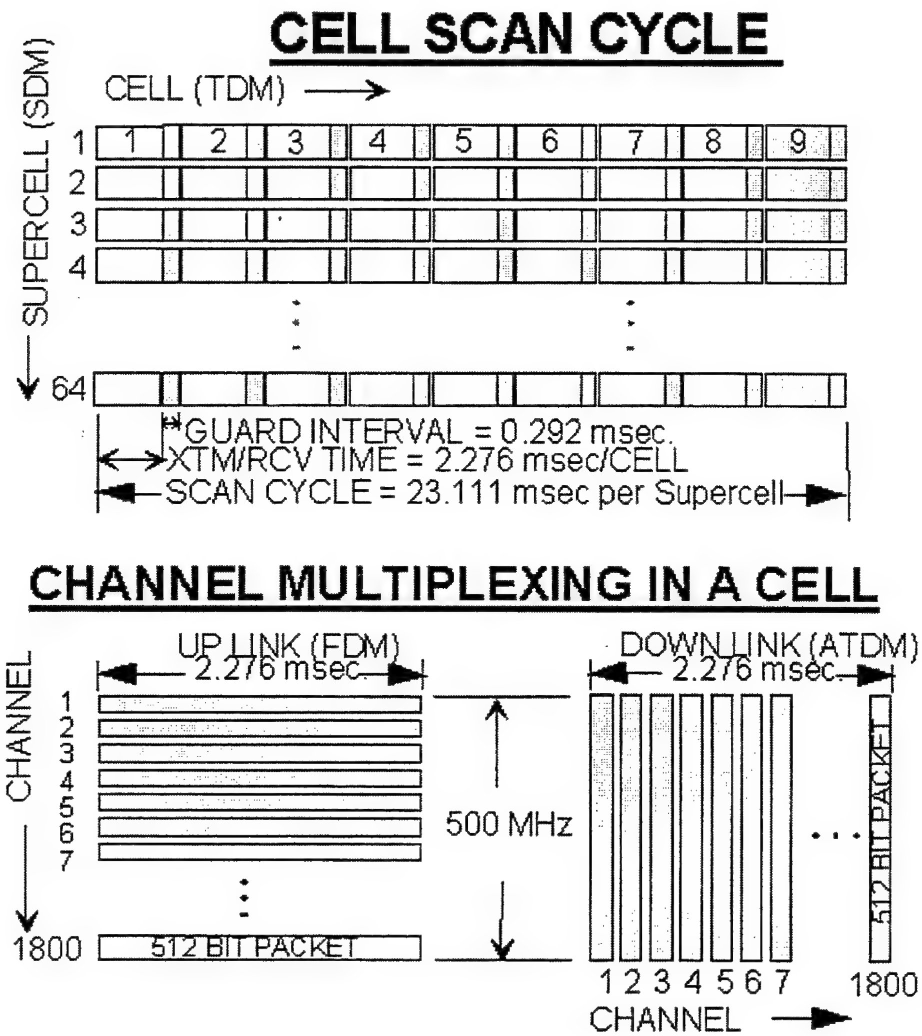

Figure 3-8 Teledesic' s Standard Terminal Multiple Access Method. From Ref. [20].

The terminal downlink uses the packet 's header rather than a fixed assignment of time slots to address terminals. During each cell's scan interval the satellite transmits a series of packets addressed to terminals within that cell. Packets are delimited by a unique bit pattern, and a terminal selects those addressed to it by examining each

packet's address field. A Standard Terminal operating at 16 kbps requires one packet per scan interval. The downlink capacity is 1800 packets per cell per scan interval. The satellite transmits only as long as it takes to send the packets queued for a cell.

To make efficient use of the radio spectrum, frequencies are allocated dynamically and reused many times within each satellite footprint. The Teledesic system will reuse its requested spectrum over 350 times in the continental U.S. and 20,000 times across the Earth's surface. The Teledesic Network supports bandwidth-on-demand, allowing a user to request and release capacity as needed. This enables users to pay only for the capacity they actually use, and for the Network to support a much higher number of users. Thus, the Teledesic Network is designed to support millions of simultaneous users. The Network scales gracefully to a much higher capacity by adding additional satellites.

10. Satellite and Launch Overview

The Teledesic satellite is specifically designed to take advantage of the economies that result from high volume production and launch. All satellites are identical and use technologies and components that allow a high degree of

automation for both production and test. To minimize launch cost and the deployment interval, the satellites are designed to be compatible with over twenty existing international launch systems, and to be stacked so that multiple satellites can be launched on a single vehicle. Individual satellites, the constellation as a whole, and the COCCs are designed to operate with a high degree of autonomy.

The initial constellation includes a number of active on-orbit spares that can be used to "repair" the Network immediately if a satellite is removed from service temporarily or permanently. Routine periodic launches will be used to maintain an appropriate level of spares in each orbit plane. Launch vehicles and satellites that have reached the end of their useful life are deorbited. They disintegrate harmlessly on re-entry, and will not create space debris.

11. LEO vs GEO Communication Satellite Latency

Quality-of-Service (QOS) is essential to the current and future telecommunications. QOS refers to the performance guarantees that a network can offer to its users, which determines what the network can be used for. Latency - which simply means delay - is one of the basic parameters that determines a network's QOS. Teledesic's predicted ability to

offer fiber-like latency to ensure seamless compatibility with terrestrial networks is an important competitive advantage over traditional, high-latency geostationary satellites.

Latency in voice communications becomes noticeable with a round-trip delay of 100 to 200 msec. Because of their great distances from Earth, GEOs have minimum round-trip latency of 500 msec. Latency also has an effect on client/server protocols. Client/server protocols rely on "transaction-oriented" application-layer protocols that consist of large numbers of low bandwidth requests and responses. Additionally, using modern "challenge-response" authentication protocols and performing address lookups using the Domain Name System (which occurs before all Internet connections are established) also require numerous low-bandwidth round-trips. (Ref. 25: p. 1, Ref. 30: p.4)

These protocols were developed on and deployed over low-latency LANs and WANs. The protocols they employ are optimized on a number of factors (e.g., allowing "roll-back" of unconfirmed transactions, low use of bandwidth, stateless transactions, etc.). However, minimizing the number of round-trips is rarely if ever one of the factors taken into account in a protocols design.

This fact can result in unacceptable performance over GEO networks. For example, accessing and updating a customer record from an SQL Server across the country may take 20 round-trip transactions. Over a fiber connection (or Teledesic), this will take between 0.75 and 1.5 seconds. Over a GEO, it will take at least 10 seconds. Both networks may be offering the same nominal bandwidth, but the GEO communication can take many times longer because of the inefficiency of performing multiple small transactions over a high-delay network.

It turns out that the majority of protocols running over the Internet and intranets are adversely affected by high-latency connections. Two of the most important standards in computing today provide examples. Transmission Control Protocol (TCP) is the standard transport protocol for networking, and the World Wide Web is the fastest growing network application in history, widely recognized as the new medium for collaboration and commerce. Both are intrinsic to the Internet and intranets, yet neither works well over geostationary links.

TCP/IP is the protocol suite underlying the Internet and all intranets. It is so fundamental to the operation of the Internet, that one of the best technical definitions of the Internet is "the network of interlinked computers

running the TCP/IP protocol suite". TCP is a reliable data protocol; it guarantees that the data will arrive in the same form it was sent, without loss or corruption. Like most protocols, TCP splits the data into segments, " packets," and then reassembles them in the same order on the other side of the link. This way, if any data is lost in transit, the missing packets can simply be retransmitted. However, this requires that all unacknowledged packets be stored on the transmitting computer until confirmation is received that the packets arrived successfully. To confirm successful transmission, TCP utilizes acknowledgement packets, where the recipient indicates essentially "I've correctly received the data so far; please continue." The time it takes to send some data and get an acknowledgement back is the round-trip delay, or latency, of the connection. (Ref. 31: pp. 260-261)

There are three main issues regarding latency in Internet protocols:

1) The default "window size" in many TCP/IP protocol implementations act as a bottleneck on communications over high-latency links. The window size represents the amount of information being stored in case a transmission error occurs. On many implementations, the standard window prevents sending enough data to fill a high-latency connection. For example, the default buffer size in both the

Windows 95 and Windows NT implementations of TCP/IP is 64 kilobits. This means that at any given moment, only 64 kilobits can be in transit and awaiting acknowledgment. No matter how many bits a GEO link theoretically can transmit, it still takes at least half a second for any 64 kilobits to be acknowledged. So, the maximum data throughput rate is 64 kilobits per 1/2 second, or 128 kbps. The impact for users is that over a 2 Mbps GEO link, one would expect to be able to transmit about 2 Mbps worth of data. In fact, any connection via a geostationary satellite would be constrained to only 128 kbps, which is less than 7% of the purchased capacity. (Ref. 25: p.1)

There are technical approaches to resolving this issue (e.g., RFC 1323, which enables larger windows), but they are not widely deployed and may not be feasible in many situations (e.g., a busy web server may not have the memory to support numerous large window connections). Moreover, because TCP is an end-to-end protocol, trying to fix latency issues requires modifying the protocols of every computer with which one might want to communicate. Network managers do not want to have to modify their protocols or installed base to deal with non-standard networks.

2) TCP includes two essential congestion control mechanisms called "slow start" and "congestion avoidance."

These mean that all Internet connections (such as viewing web pages and sending e-mail) start out at lower bandwidth and then throttle up to higher speed if no congestion is encountered. The problem is that each cycle of speed increase requires a full round-trip communication between sender and receiver, and dozens of such round-trips can be necessary to reach the full potential of a link. When a round-trip takes 500 msec or more, as is the case with a GEO, the communication often ends before the connection can ever reach the full bandwidth of the link. For instance, once the congestion avoidance algorithm kicks in, it can require 200 round-trips (which, even in ideal conditions, takes almost 2 minutes) for a GEO link to get back up to T1 bandwidth. Most likely, the transmission will have ended by then, with the information having been transferred at sub-optimal rates. (Ref. 25: p.1)

There is research underway to better understand this issue, but it is unlikely that the slow start and congestion avoidance mechanisms can be removed from TCP without causing a "congestive collapse" of the Internet.

3) There are research efforts to look at increasing the performance of TCP over GEOs by "spoofing" the connection to trick the other side into believing it is communicating with a low-latency link. Unfortunately, these schemes

fundamentally alter the semantics of TCP communications, introducing the possibility of data corruption. Moreover, they are incompatible with the IP security protocols (IPsec), which promise to bring an unprecedented and badly needed degree of security to the Internet. The next generation Internet Protocol, IPv6, which mandates the use of IPsec authentication, will not function over a spoofed link. (Ref. 25: p.1)

There is a wide consensus that TCP/IP is one of the most important and widely distributed technologies in modern networking. But many other networking technologies have even greater problems with high latency. For example, the standard mainframe and minicomputer communications protocols - SNA and DEC LAT - generally will not work at all over high-latency links.

The difference between Teledesic and GEO latency - GEOs have five to 25 times more delay than Teledesic - is more important than the simple ratio makes clear. This is because protocols and applications are not designed for zero-delay networks; they are designed for today's real-world terrestrial networks, for which fiber sets the standard. Teledesic is designed to have the same essential QOS characteristics as fiber. That means that applications and protocols that work over fiber will work the same way over

Teledesic. The point is for the application not to know it's going over a satellite. Teledesic can act as a seamless extension of the Internet and other terrestrial networks. As soon as you move away from the QOS available on terrestrial networks, that seamless compatibility no longer holds, and applications can start breaking.

One of the fundamental principles of the Internet is the notion of all applications moving on to a common network platform - an open network based on common standards and protocols. This is also the idea behind IT-21's Naval Virtual Internet. The idea of stand-alone, proprietary networks, or application-specific networks, is fast disappearing. All applications will move over the same networks, using the same protocols. In these packet-switched networks - where voice, video, and data are all just packets of digitized bits - it is not practical to separate out applications that can tolerate delay from those that cannot. As a result, the network should be designed for the most demanding application.

For the reasons described above, latency is one of the most important criteria in evaluating the QOS of a communications link. Major Internet Service Providers (ISPs) are responding to the demand for high-quality service by offering guarantees of low-latency performance. For example:

- UUNET guarantees less than 150 msec end-to-end latency for two sites on its network.
- Concentric guarantees less than 150 msec end-to-end latency for two sites on its network.
- AT&T WorldNet guarantees less than 100 msec latency on its backbone.
- Sprint guarantees less than 140 msec latency on its backbone.

Finally, the Automotive Network Exchange (ANX) has begun a program to accredit Certified Service Providers that will provide TCP/IP-based Virtual Private Networks for connecting auto makers and their suppliers. This rigorous certification program will involve ongoing compliance testing of more than 100 different service criteria such as availability and throughput. The ANX is one of the most important things happening to evolve the Internet for business. (Ref. 25: p.1)

The ANX will mandate that the maximum allowable latency for connections is 125 msec. This figure came directly from analyzing the demands of the auto industry's mission-critical applications.

Additionally, ANX will rely on IPsec and will specifically forbid spoofed packets. This will make it nearly impossible for service providers using GEO links to

become Certified Service Providers. Over time, customers expect more from communications links, just as they do from software. Thus, it is likely that these guarantees will only grow more stringent as more and more mission-critical applications are migrated to the Internet and QOS-guaranteed Virtual Private Networks such as the ANX.

The QOS guarantees that major ISPs are beginning to make are already setting a standard that Teledesic will have to meet. Teledesic's approach is to conform its network to the market requirements rather than require that the market conform to the limitations of a GEO. Teledesic's Internet-in-the-Sky is designed to provide end-to-end QOS that enables global enterprise networking, meeting the demands of the Internet of the future. QOS design parameters include:

- Multi-megabit, Bandwidth-on-Demand (BoD).
  Terminals will be able to request and release capacity in less than 50 msec, resulting in extremely efficient statistical multiplexing. One of the most compelling aspects of a "shared-bus" communications medium such as many wireless systems is the ability to offer Bandwidth-on-Demand (BoD). It is also one of DoD's functional requirements for wideband communications. BoD allows a user to request and release capacity as needed. For example,

the pause between sentences in an Internet telephone transmission can be used to transmit best-effort services such as e-mail. This statistical multiplexing (allowing several users to share a network resource) is only feasible if both transmitters (user terminals) can dynamically negotiate bandwidth demands with the network (satellites). The high latency in a geostationary satellite system drastically reduces the efficiency of any statistical multiplexing because by the time the resources can be scheduled, they may no longer be available.

- Fiber-like Bit Error Rates (BER).

  Use of Forward Error Control (FEC) will provide BER of less than 10^{-9}, creating an essentially noise-free channel. Fiber-like availability of 99.9% or higher, enabled by Teledesic's 40 degree elevation angle among other features, will provide higher uptime than many terrestrial links. End-to-end (one-way) latency will be as low as 20 msec and less than 75 msec on all links of less than 5,000km. Round-trip (two-way) latency will be less than 100 msec on most connections. (Ref. 25: p. 1)

When evaluating GEO versus LEO wideband satellite links, DoD will need to decide whether they are willing to make do with bandwidth constraints, protocol hassles, and "choppy" real-time applications, or whether they want connections with the same essential characteristics of fiber. With the Teledesic network it will be able to ensure the compatibility of the entire installed base of network equipment with which one might want to communicate, receive seamless compatibility with the standard, fiber-based terrestrial networks.

Any specific latency problem in a protocol or application may be individually solvable. But when taken together, these problems are indicative of the business risks of building networks that diverge from terrestrial standards. What network developer wants to take the chance that the next applicable software application - or the one after that - will simply not work over his network? By deploying a network that is seamlessly compatible with fiber, Teledesic can help ensure that customers can use the next generation of applications - whatever they may be and wherever they are needed.

Teledesic's quality of service advantage is compounded by a projected service cost three to four times lower than geostationary systems. Also Teledesic is a full duplex

wideband communications system, vice the simplex GEO wideband systems (GBS and Challenge Athena) supplementing military communications today. For the future of military communications Teledesic appears to be a promising addition to the DoD SATCOM architecture.

IV. MILITARY APPLICATIONS FOR THE TELEDESIC SYSTEM

A. COMMERCIAL SATELLITE COMMUNICATIONS INITIATIVE

The requirement to rapidly communicate over long distances has resulted in an increased dependence upon satellite communications for DoD operations. During Operations Desert Shield and Desert Storm and as recent as Operation Joint Endeavor in Bosnia, communications planners realized existing MILSATCOM systems lacked sufficient capacity to support the enormous communications requirements for JTF command operations. As a result, an integrated architecture using commercial satellite communications systems to augment existing, overburdened, military communications systems is being pursued to resolve today's shortfalls.

At the urging of Congress in 1992, DoD began the Commercial Satellite Communications Initiative to investigate ways in which the DoD could more effectively, and more inexpensively, make use of substantial on-orbit commercial communications capacity and thereby lessen its reliance on military systems. The first outgrowth of that study was the DoD's 1993 policy on the use of commercial SATCOM.

Under the Commercial Satellite Communications Initiative (CSCI) DoD planned to lease transponders, not connections, on more than a single satellite and from the system owner, not from the communications service provider. DoD would then set up its own "commercial" network, which it could control. The plan is to integrate control for that DoD network parallel to our DSCS network control. That way, DoD will have a rapid and coordinated transfer of services between our CSCI network and our military SHF system. (Ref. 32 p.14)

Following in the spirit of the CSCI, the U.S. Navy has been aggressively pursuing the use of commercial wideband satellite communications systems as an augmentation to existing military systems. The CNO Special Project Challenge Athena's goal has been to provide the necessary communications throughout the fleet to allow JTF commanders afloat the ability to actively participate in joint command decisions and operations. In the future visions of Joint Vision 2010 and the Navy's Information Technology for the 21^{st} Century (IT-21), the increased bandwidth and area coverage requirements that can be met by the Teledesic system will dramatically enhance MILSATCOM systems. The integration of the Teledesic commercial wideband satellite communications system into the MILSATCOM architecture will

also provide an augmentation or surge capability during contingency operations.

B. FUTURE VISION

An outgrowth of the National Security Strategy, Joint Vision 2010 is the DoD's view of future warfighting. IT-21 is a Navy Department vision of communications network architecture to enable implementation of the visions of JV 2010. The following paragraphs will explain the DoD visions of the future and how the Teledesic system can be integrated into the military information networks.

1. Joint Vision 2010

The goal of Joint Vision 2010 is to provide warfighters with accurate information in a timely manner. Information technology improves the ability to see, prioritize, and assess information. The fusion of all-source intelligence with sensors, platforms, command centers, and logistics support centers will allow operations to move faster. Advances in computer processing and the global network umbrella of the Teledesic system could provide the capability to collect, process and display relevant, fused data to thousands of locations simultaneously. This integrated military SATCOM system will ensure that the data

is distributed on a real-time basis, making it possible for warfighters to use information most effectively.

Joint Vision 2010 (JV 2010) is the conceptual template for how our forces will achieve dominance across the full range of military operations in the future. This vision of future warfighting embodies the improved intelligence and C4 available in the information age and goes on to develop the following four operational concepts:

- Dominant Maneuver
- Precision Engagement
- Full-Dimension Protection
- Focused Logistics

One observation is that the four emerging operational concepts of JV2010 mentioned above can potentially be enabled by operational architectures that closely couple the capabilities of sensors, C4 and shooters. The emerging operational concepts of JV2010 can be characterized as "Network Centric" and the vision of future warfare as "Network Centric Warfare." (Ref. 33: p. 1)

One example of an existing operational architecture that employs network centric operations to increase combat power is the Cooperative Engagement Capability (CEC). The operational architecture of CEC increases combat power by networking the sensor, C4 and shooters of the CVBGs

platforms to develop a sensor engagement grid. The CEC sensor grid fuses data from multiple sensors thereby enabling quantum improvements in timeliness, track accuracy, continuity and Target ID over stand alone sensors. The engagement grid exploits high levels of awareness to generate increased combat power by extending the battlespace and engaging incoming targets in depth with multiple shooter and increased probability of kill. (Ref. 33: p. 2)

To provide the networking communications bandwidth required for the integration of sensors and weapons systems, a robust and flexible communications system such as Teledesic would be a preliminary requirement. The Teledesic systems could be integrated into the idea of Network Centric Warfare as part of the information grid.

2. IT - 21

Information dominance is the foundation of joint vision 2010, as well as the warfighting vision for each service. Network Centric Warfare, robust infrastructure and information dissemination to dispersed forces are key elements in achieving information dominance. IT-21 is a fleet driven reprioritization of C4I programs of record to accelerate the transition to a PC-based tactical warfighting and tactical support network.

Fleet Commands have challenged the Navy Engineering Commands to provide an approach that will modernize the Fleet Theaters to meet the information requirements of the future. The approach must address a transition from the specialized and dedicated work-station of today into an open architecture that:

- Is based on the personal computer (PC)
- Provides a convergence of tactical and non-tactical operations
- Is based on common communication systems
- Uses a scalable communication backbone, compatible with the DII, to transfer the information
- Incorporates a leading edge logistics and maintenance system
- Is based on COTS equipment
- And makes good business sense (is cost effective both initially and long term).

The goal of IT-21 is to create a cost effective, technologically advanced information infrastructure that enables the Naval user to sit at a PC (either ashore or afloat) and perform all required job functions and administrative applications throughout all Areas Of Responsibility (AORs). IT-21 accommodates the movement of databases ashore and allows afloat users to "pull"

information as needed. Theater command and control, e-mail, World Wide Web browsing, Defense Message System, tactical and non-tactical data must share the same information resource environment in order to reduce operating costs. The infrastructure must support the increase in data that will occur as commands start to consolidate functions such as weather, disbursing, travel and logistics. The communications transition between a deployed ship, and a ship pierside should be invisible to the user (with the exception of the slower response time while deployed due to the bandwidth limitation of satellite resources). (Ref. 33: p. 3)

To reduce the bandwidth limitations and use of MILSATCOM resources used in the IT-21 architecture, the Teledesic wideband communication system could be integrated into the military network. Teledesic could provide the networking for Internet functions such as email and the World Wide Web as well as transport for tactical and non-tactical data. Teledesic will provide a full duplex system for "user pull" of information. The Teledesic system's low latency will allow it to use standard Internet protocols for ease of systems integration and the use of off-of-the shelf applications, all goals of IT-21.

a) IT-21 Promotes Joint Interoperability

IT-21 leverages DoD's investment in satellite communications systems by increasing the ability to handle the increasing SATCOM data rates being made available to ships and submarines. The IT-21 strategy provides as end-to-end capability in terms of throughput, reach-back, processing, security and distribution of information throughout the ship.

Basic military programs that enable IT-21 are Global Command Control System - Maritime (GCCS-M) and Defense Messaging System (DMS). Navy's version of GCCS, Joint Maritime Communications Information System (JMCIS), is being upgraded rapidly to be compliant with the Defense Information Infrastructure Common Operating Environment (DII COE) and will soon be re-designated as GCCS-M. The current DoD messaging system (AUTODIN) will be inactivated by Dec 99, with no planned Navy infrastructure replacement, which means the Defense Messaging System (DMS) must be implemented by that date allowing interoperability between services. (Ref. 33: p. 4)

A number of programs and standards support the IT-21 strategy and improve or enable interoperability between naval and joint forces.

(1) GCCS-M. JMCIS (Joint Maritime Communications Information System) is an integrated C4I System for storage, processing and display of the common operational picture. As the Navy's GCCS, the latest version of JMCIS will be compliant with the GCCS software core and the entire DII Common Operating Environment. The compliance to DII COE enables the JMCIS to be fully Joint interoperable.

(2) Defense Messaging System (DMS): The DMS is a secure, reliable standards-based message system that uses mainline commercial products. DMS-compliant messaging provides high-assurance interoperability within DoD, the national intelligence community, NATO/Allied partners and some federal agencies. DMS will provide a global directory and public key infrastructure that can be used by other DII applications. DMS will replace the obsolete technology of the Automatic Digital Network (AUTODIN) message system.

(3) Standardized Tactical Entry Point (STEP): The STEP program was developed to resolve warfighter concerns about global standardized C4I services and systems supporting tactical forces. STEP is a Joint Staff/DISA initiative to better utilize existing Defense Satellite Communications System strategic earth terminals by providing a standardized

set of pre-positioned equipment for connectivity into the DISN, NIPRNet and SIPRNet, and shore-based voice and video links. The STEP program enhances facilities at certain DSCS gateways by adding tactical interface equipment that will allow the JTF commander and his forces to access standardized C4I services on the DISN backbone from anywhere in the world. (Ref. 33: p. 4)

(4) Base Level Infrastructure Improvement (BLII) Program: A modernization program directed at the base level to support the warfighter. The BLII includes inside and outside cable plants (wire or fiber optic) and any equipment connected that is installed as an integral part of the base infrastructure such as telephone sytems, network concentrators, routers and servers. Target areas include high speed data communications, fielding of DMS, full interoperability with the DISN, flexible growth, and manageability from central locations.

(5) The JMCOMS (Joint Maritime Communications Strategy) is a technical and program strategy which implements the communications segment of the Navy's Copernicus C4I architecture. JMCOMS incorporates the latest advances in commercial and military communications technology to

maximize bandwidth, enabling the sharing of information seamlessly, in real-or near real-time, through flexible, adaptive, and interoperable systems and services. JMCOMS provides both tactical improvements to the warfighter and non-tactical quality of life services to sailors at sea and ashore. JMCOMS' rapid, reliable, and reconfigurable communications connectivity to all echelons of command and its accompanying information transfer infrastructure make the sensor-to-shooter construct a reality in the C4I environment. The driving forces behind the strategy include: emergence of information superiority as foundation for all operational concepts; interoperable communications; and the continuing emphasis on acquisition streamlining. The three major elements of JMCOMS are Automated Digital Network System (ADNS), Digital Modular Radio (DMR), and the Integrated Terminal Program (ITP). (Ref. 33: p. 5)

- ADNS is the backbone of JMCOMS. ADNS provides routing and switching of user data to RF transmission circuits, manages data exchange over the RF circuits and networks, and monitors network quality of service. It will provide timely data delivery service to/from all data user sources (Navy, Joint and Allied) via the DMR and ITP radio terminals. ADNS is based on COTS and government off-

the-shelf (GOTS) networking hardware and software, such as Internet Protocol (IP) routers and ISDN and Asynchronous Transfer Mode (ATM) switches.

- DMR is a software configurable, digital radio with multi-function antennas and RF distribution systems. Radio operates at frequencies less than 2 Ghz supporting both tactical terrestrial and SATCOM requirements.
- ITP is a strategy to migrate current stovepipe SATCOM systems, which operate above 2 Ghz to open architecture, modular, multi-band terminals and low observable, multi-function antennas. Provides interface to DSCS, Milstar, UFO/E
- And commercial SATCOM.

JMCOMS will provide joint and allied interoperability through the implementation of the DoD JTA (Joint Technical Architecture) and the use of established commercial and military networking standards. JTA is the DoD-level technical architecture "defining a minimal set of rules governing the arrangement, interaction, and interdependence of the parts or elements, whose purpose is to ensure that a conforming system satisfies a specific set of requirements. It identifies system services, interfaces, standards, and their relationships." JTA currently consists

of interface standards and protocols for information transport, content and format, and information processing. It identifies a common set of mandatory information technology standards and guidelines to be used in all new and upgraded C4I acquisitions across DoD. JMCOMS will interface with the SIPRNet/NIPERNet through the evolving shore communications infrastructure. JMCOMS IP networks will also interface either directly or through Standardized Tactical Entry Points (STEP) to the packet data networks of the other services to include the Armies "Enterprise" Network and the Air Forces "Horizon" Network. (Ref.33: p. 5)

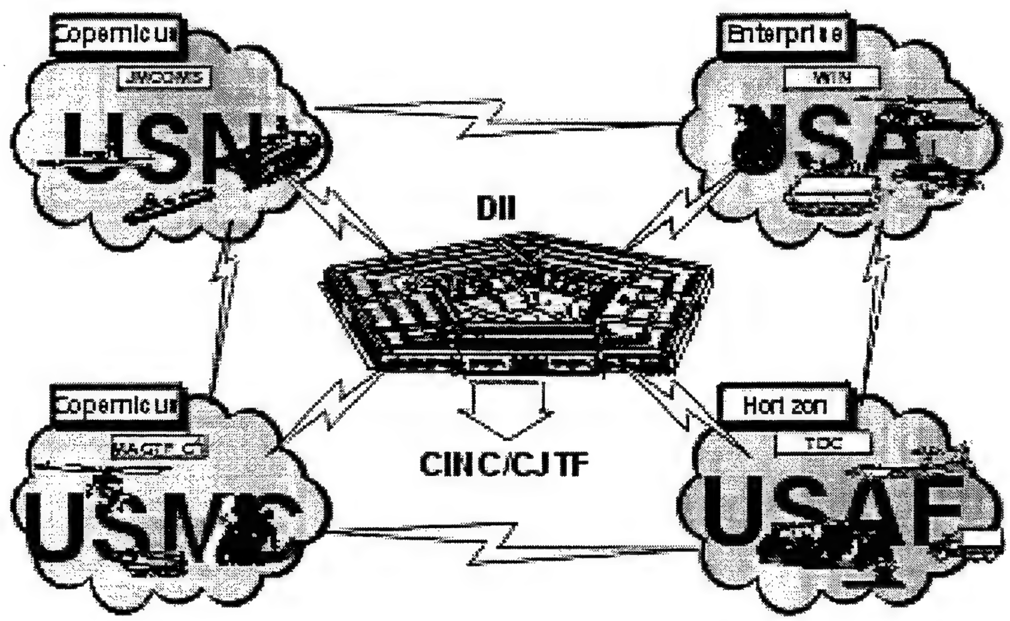

Figure 4-1 DoD Integrated Network. From Ref.[34].

C. MILITARY INTEGRATION OF TELEDESIC

1. Automated Digital Network System (ADNS)

The Automated Digital Network System (ADNS) is the backbone to JMCOMS. ADNS uses off the shelf protocols, processors and routers to create a robust and flexible networking environment. The ADNS will provide timely information delivery service (voice, video, and data) to/from all user systems (Navy, Allied and Joint). Internet Protocols (IP), Asynchronous Transfer Mode (ATM) and other products are being adopted or adapted from the commercial telecommunications world. It is within the ADNS that integration of the Teledesic System into the MILSATCOM architecture can take place. Interfaces to all RF media from HF to EHF in the ADNS provides the total throughput and access needed. At the same time, networking techniques make efficient use of all available channels.

ADNS furnishes autonomous, digital, interoperable, joint and secure LAN/WAN management and control for RF assets on demand to Navy deployed personnel aboard ships and at shore sites. The ADNS system ensures worldwide communications connectivity via RF assets. It automates all communications systems replacing several unique sub-networks with a single integrated network hub. It will also apply Non-Development Items (NDI) COTS/GOTS router, switching and

packet data technologies enabling reduced life cycle costs. The integration of COTS/GOTS significantly reduces ADNS development, procurement, and maintenance costs.

ADNS is composed of three functional elements: Routing and Switching (R&S), Channel Access Protocols (CAP) and the Integrated Network Management (INM). The R&S subsystem provides the interface to users, and performs routing and switching of user data to available transmission circuits. The objective R&S subsystem includes a COTS IP router, a suite of common packet routing protocols and COTS Integrated Services Digital Network (ISDN) and ATM switches. CAP equipment manages data exchange over JMCOMS circuits and networks, monitors network quality of service, and reports loading and error conditions to the INM. The INM provides the flexibility to adapt communications to available assets and mission priorities. It uses COTS software and resides on TAC-4 workstations. (Ref. 35)

ADNS will operate at the Secret High General Service (GENSER) classification level. Initially data streams from multiple security levels (unclassified to Top Secret Special Compartmented Information (SCI)) will be connected and kept separate by cryptographic separation using the COTS Network Encryption System (NES). Users may also interface directly

to ADNS via accredited Multiple Level Secure (MLS) LANs or embedded MLS products.

a) Routing and Switching (R&S)

The ADNS R&S subsystem will provide the interface to the end user and routing and switching of user voice and data across available RF transmission resources, which could include Teledesic. The objective R&S subsystem will include an IP router, and ISDN and ATM switches similar to the Teledesic system. The ADNS packet data subsystem will implement IP addressing and routing for data exchange over JMCOMS RF resources. The top level ADNS PDS functional block diagram is shown in Figure 4-2.

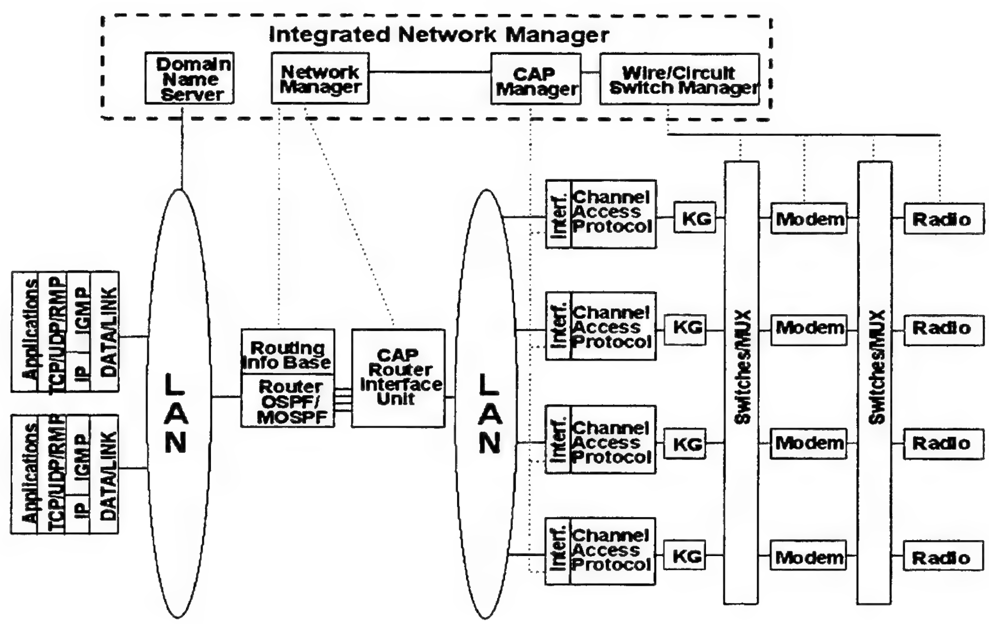

Figure 4-2, ADNS Packet Data Subsystem. From Ref [35]

ADNS Packet Data Subsystem (PDS) is based on products developed in the Communications Systems Network Interoperability (CSNI) program and the Military Internet Multicast (MIM) and Internet Protocol Addressing (IPADD) programs. These programs produced the products fielded during JWID 95 on USS KITTY HAWK, USS COWPENS and Naval Computer and Telecommunications Area Master Station (NCTAMS) EASTPAC. ADNS PDS uses COTS IP routers to maximize the efficient use of standard Internet protocols over Navy subnets. The use of standard Internet protocols enables Navy systems to use off-the-self-applications, which is also a goal compatible with the Teledesic system. (Ref. 35)

Applications which have a clearly defined transport layer interface such as e-mail, File Transfer Protocol (FTP) and X.400 messaging, operate on a connection oriented basis and use Transmission Control Protocol (TCP). These applications include Navy Modular Automated Communications Systems (NAVMACS)/DMS, TOMAHAWK, Tactical Intelligence Information Exchange Subsystem (TACINTEL) and selected e-mail applications. The multicast features of joining groups, Class D IP address mapping to group names, and low/congestion control need to be integrated into host applications. These applications include Joint Maritime

Command Information System (JMCIS) and any other application that does not use TCP as the transport layer. (Ref. 35)

The Channel Access Protocol Router Interface Unit (CRIU) provides the physical interface between the IP router and the CAP for each media. The CRIU also performs data buffering and framing as required to ensure efficient data flow across the RF link. The CRIU also conducts prioritization of outgoing traffic and routing to the appropriate RF circuit through its CAP. It is through software of the CRIU that decisions could be made to route information to the Teledesic Network or to MILSATCOM.

CAP equipment will manage data exchange over JMCOMS circuits and networks, monitor network quality of service and report loading and error conditions to the R/CM. The CAP interface is most important for dynamic routing, as the CAPs provide the subnet performance statistics necessary for metric value calculation by the network manager. The CAP also provides the interface between the RF circuits and the ADNS system. It is through the development of a Teledesic ADNS CAP that DoD Teledesic data packets can be integrated into the shipboard LAN or WAN. (Ref. 35)

ADNS and Teledesic both send data based on using the Open Shortest Path First/Multicast Open Shortest Path First (OSPF/MOSPF) and routing protocols which allow for

dynamic route selection based on metric values (capacity, delay, reliability and cost). The OSPF protocol defines Autonomous System domains, areas and backbone networks to minimize the distribution of routing information. The ADNS objective communications architecture is shown in Figure 4-3.

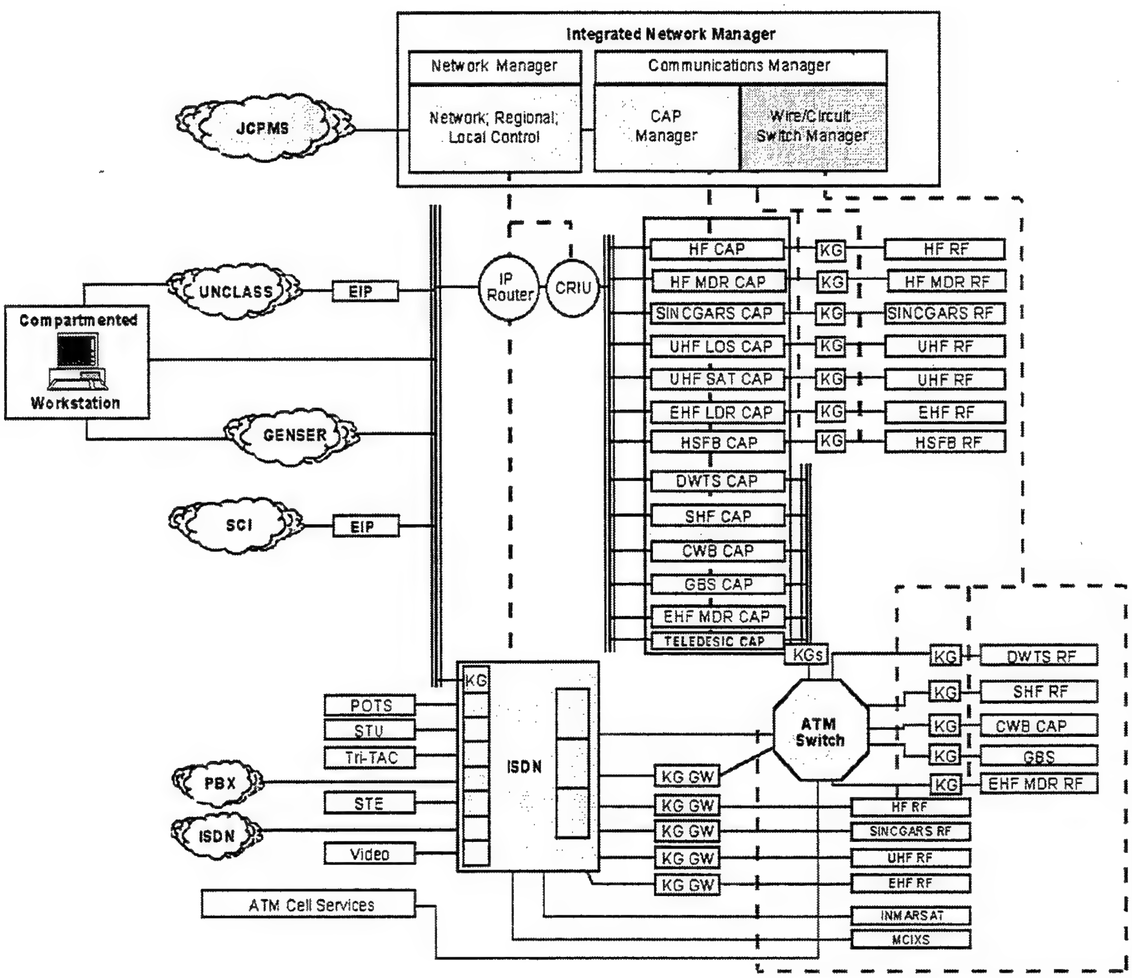

Figure 4-3, ADNS Objective Architecture with Teledesic CAP. After Ref. [35].

b) Integrated Network Management

The Integrated Network Manager (INM) will be hosted on a Unix workstation (planned migration to Windows NT), with a remote capability (local or off site) provided by COTS network management software. The Operations Concept for ADNS INM is defined in the Automated Integrated Communication System (AICS) Network Management Architecture (NMA). It is within the INM system that Teledesic Gateways could be integrated into the system to provide DoD control of the data sent. The Network Manager will provide three levels of management: (Ref. 36: p. 1)

Level 1 is the Local Operations Center (LOC) which manages individual area assets (afloat and ashore) that can be monitored and controlled through use of commercially available, standards based management protocols such as Simple Network Management Protocols (SNMP). Almost all IP router network products are manageable by SNMP, and most switch products are also manageable by SNMP. LOCs could be placed at the lowest echelons and provide the gateways for the Teledesic system. Four Teledesic 16 kbps basic channels could be summed to provide the 64 kbps desired to the unit level by IT-21.

Level 2 will be the Regional Operations Center (ROC), which may be afloat and ashore. LOC managers operationally assigned under the ROC will be monitored by the ROC. Except in very exceptional cases, control remains a function of the LOC (see Figure 4-4). Depending on the desired bandwidth, Teledesic channels could be summed to provide any surge requirements in the region.

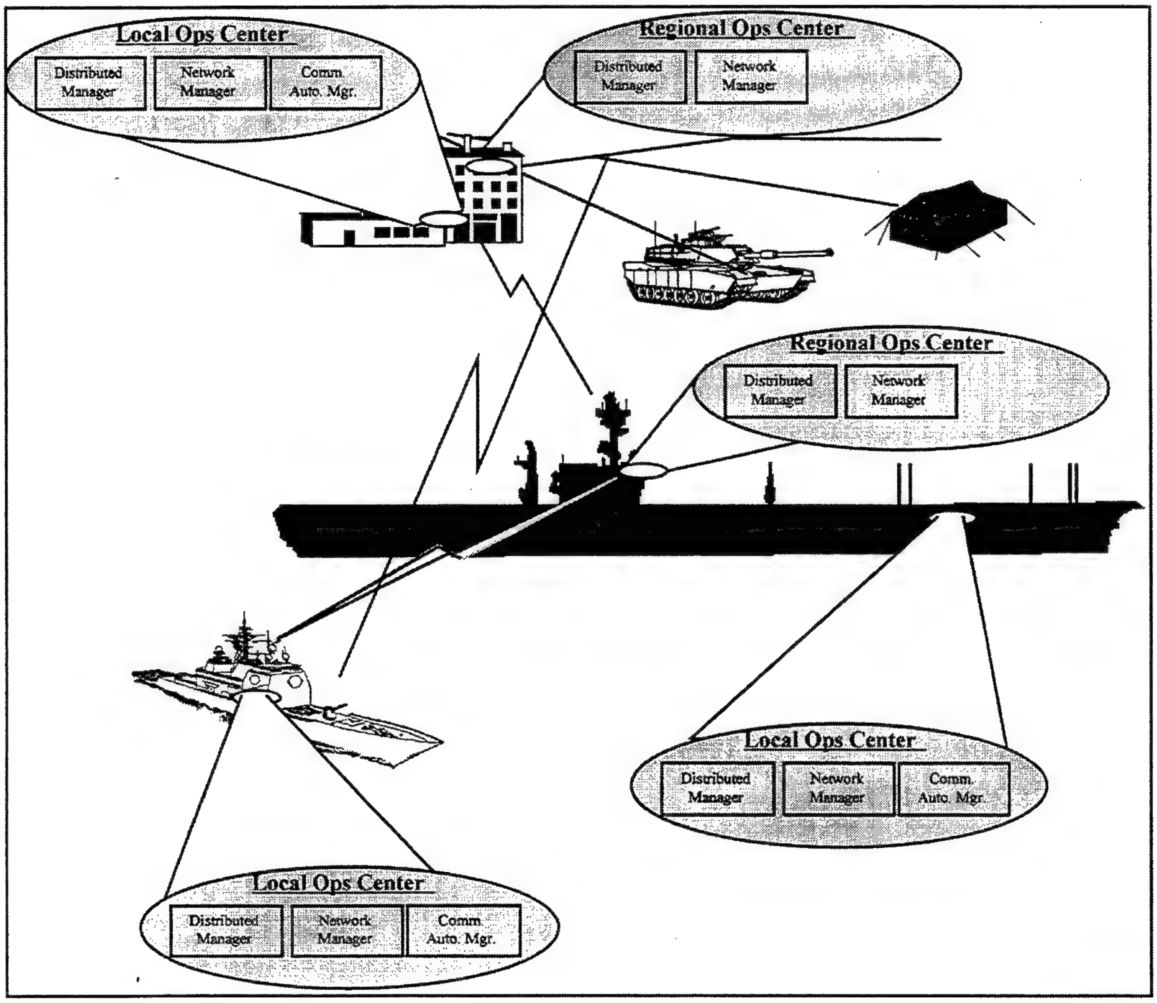

Figure 4-4, LOC & ROC Relationship. From Ref. [36].

Level 3 is the Network Operations Center (NOC). The NOC is normally located at the Naval Computer and Telecommunications Area Master Station. The NOC monitors operations on behalf of the Fleet Commander in Chief or Naval Force (NAVFOR) Commander. The NOC is the point of network management information exchange with Defense Information Infrastructure (DII) network management. These centers will provide the interface between the satellite and terrestrial communications systems where each NOC functions as a network manager much as an Internet manager. Each region's NOC is responsible for communications between deployed forces and in-garrison forces via the satellite and terrestrial networks. Deployed forces may communicate via various media such as ultra high frequency, super high frequency, extremely high frequency or commercial service. Information passes through the regional NOC and into the terrestrial network or is turned around to another ship via the same frequency or another frequency depending on ship's accessibility, coverage zones, etc. The key aspect is the maximum efficiency of all frequencies. It is at the NOC that the main control of the DoD Teledesic Network could be maintained. By establishing a Gigabit Gateway at the NOC it will be the main interface between fleet units, the

Teledesic satellite system and terrestrial communications line (see Figure 4-5). (Ref. 35)

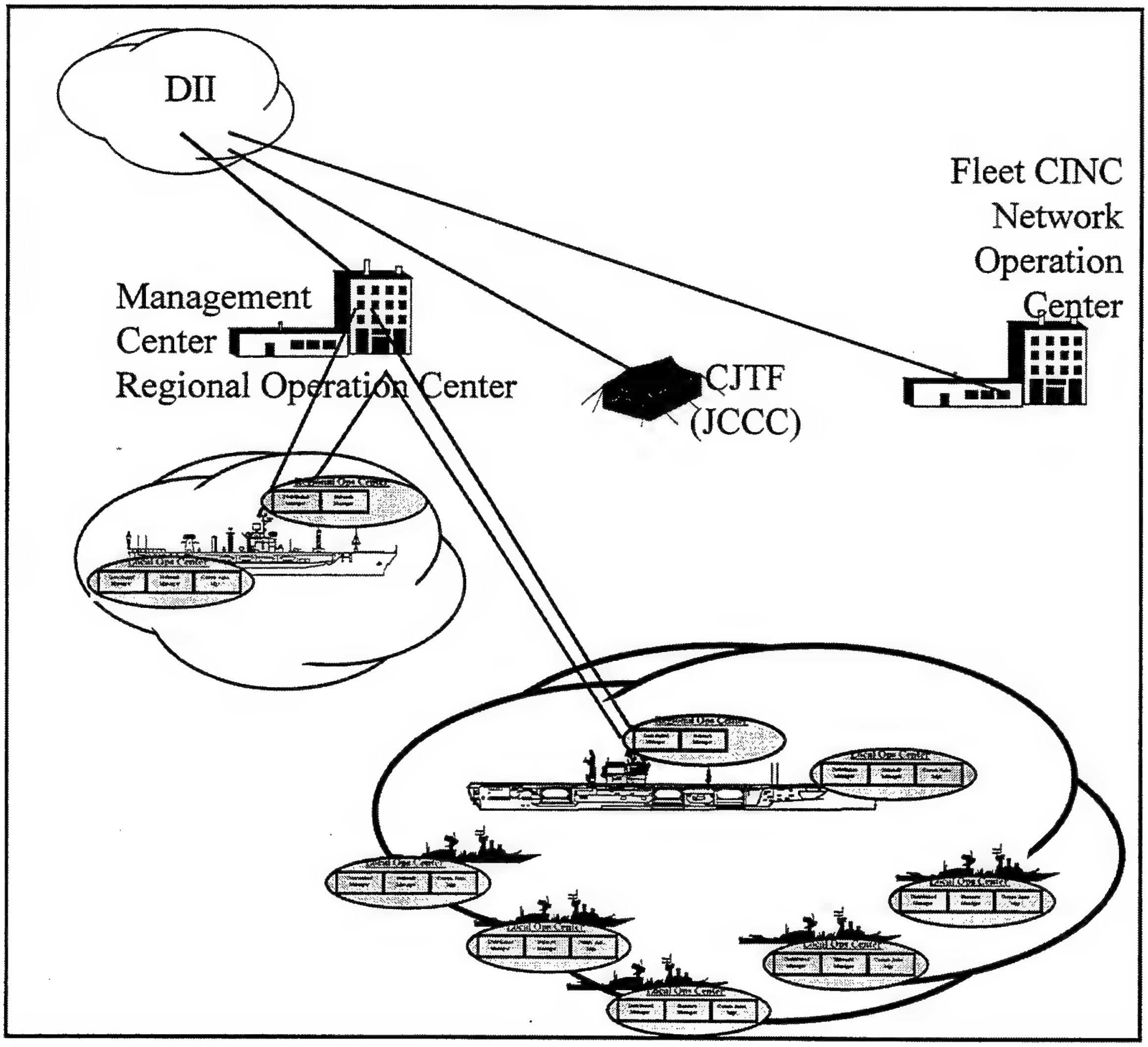

Figure 4-5, Network Operations Center Integration. From Ref. [36].

2. Integrated Terminal Program (ITP)

One of the main considerations in system development or integration is platform constraint. These considerations include but are not limited to:

- -Radar cross-section
- -Terminal Equipment: Size, Weight, and Moment
- -Antenna Size and Location
- -Stabilized Antenna required
- -Electromagnetic interference

Aboard a ship space is at a premium, especially in the placement of communications antennas. An aircraft carrier has 130 topside antennas. The Integrated Terminal Program was developed to reduce the number of topside antennas by combining several into a multi-functional system.

The Integrated Terminal Program (ITP) portion of the JMCOMS is a strategy to cost-effectively meet future requirements for high capacity satellite communications for ships, submarines, and shore commands. ITP will migrate current stovepipe SATCOM systems, which operate above 2 GHz to open architecture, modular, multi-band terminals and low observable, multifunction antennas. The ITP provides the following capabilities:

- Provides interface to DSCS, Milstar, UFO/E, and commercial satellite constellations.
- Leverages commercial technology.
- Pursues multi-functional antenna technologies aboard ships for topside space, weight and radar cross section reduction.
- Provides high-powered amplifier technology.
- Applies common electronics and components.
- Allows protected narrowband and wideband communications connectivity incorporating Anti-Jam and Low Probability of Intercept/Low Probability of Detection technologies.(Ref. 37)

The use of a commercial product such as the Teledesic system will provide access for the military to an antenna and RF source with a decrease in size and power requirements. At the same time, research to develop low observable antennas will lead to stealthier platforms as well as improved use of topside space.

a) Low-observable and Multi-function Antennas

Antennas are required that support multifunctionality and low observability to reduce ship radar cross section (RCS), lower topside weight and life

cycle cost while increasing the ability to accommodate current and future systems and maintain electromagnetic compatibility (EMC). The current proliferation of single function, large aperture antenna topside has exacerbated this requirement. Industry and government laboratories are pursuing technology improvements in planar radiating elements, multiple-beam/band reflectors and feeds, composite materials, frequency selective surfaces, radar absorbing surfaces and computational electromagnetic design tools which can be exploited to provide a topside profile that meets performance, mission and signature control requirements. (Ref. 37)

b) Technology Initiatives

The Office of Naval Research (ONR), SPAWAR's Advanced Technology Directorate, the Naval Research Laboratory and other Service laboratories are pursuing advanced antenna and radio frequency component technologies which will contribute to the future evolution of ITP systems. RDT&E efforts in multifunction and multiband apertures (under the Multibeam Multifunction Broadband Antenna project), advanced RF waveforms, solid state amplification, programmable modems and NMIC technologies are expected to reduce topside impacts, increase functionality

and possibly lower a platform's total life cycle costs. Advanced technology core programs and Advanced Technology Demonstrations (ATD) (i.e. a proposed FY98 Low Observable Multi-function Stack ATD) are being pursued to evaluate the cost and potential for phased array technology to meet the conflicting needs of reduced signature topsides and high capacity connectivity. The system designers of Teledesic are addressing similar issues and conducting the same research. If DoD decided to use the Teledesic system, research efforts could be combined to avoid duplicity and thus create a development cost savings. DoD could also then have some influence in antenna design features for its platforms. (Ref. 37)

The ITP will promote integrated topside design efforts, advanced antenna technology development and demonstrations to reduce technological risk and accelerate "producability" of affordable multifunction antennas. Incorporating with the Teledesic system can only quicken this effort. Reuse or redesign of existing shipboard apertures will be explored to lower ship impact, reduce costs and accelerate the fielding of new capabilities.

Through the ITP and ADNS, JMCOMS addresses both technical and implementation challenges of integrating Teledesic with a clear strategy. Rapid advances in

telecommunications technology and products is key. Many off the shelf products for routing, addressing, networking and network management are available and compatible with the Teledesic system.

D. MILITARY USE OF TELEDESIC

The ability to communicate at high data rates has become critical to afloat Joint Task Force command operations because the combined operation of joint systems require high data rates to quickly receive large volumes of information. For example, the Joint Service Imagery Processing System National Input Segment (JSIPS NIS), Joint Worldwide Intelligence Communications System (JWICS), Joint Deployable Intelligence Support System, Contingency theater Air Planning System and the tactical extension of joint interoperable networks available via Defense Information Support network (DISN) are programmed systems fielded on fleet units that will require high data rate communications. (Ref. 38: p.2)

JSIPS NIS is the receive element of the Defense Dissemination System which provides national imagery to strategic and tactical users. Precision-guided munitions (PGM) require high-quality broad area, national imagery to be able to find and strike their targets. The Navy, as well

as other services, is actively fielding joint tactical strike and precision-guided munitions, and the supporting mission-planning systems which require large volumes of national imagery. Broad area national imagery with accompanying exploitation support data allows precise geo-positioning for accurate targeting of many current and planned weapons systems (Tomahawk land Attack Missile, Joint Direct Attack Munitions, Joint Standoff Weapon, Standoff Land Attack Missiles, Standoff Land Attack Missiles Expanded Response, Joint Air-to Surface Standoff Missile PGMs). Additionally, large imagery files are required for tactical strike mission planning, battle damage assessment and intelligence support. (Ref. 38: p. 2)

The tactical extension of joint interoperable networks available via the DISN include the following: JWICS for Special Compartment Information interoperability; Secret Internet Protocol Router network (SIPERNET) for secret level, joint information interoperability; and the unclassified but sensitive Internet Protocol Router Network (NIPRNET) for unclassified joint information interoperability. Depending on the information classification level, the integration of the Teledesic system tactical will allow users to access these networks to exchange information between afloat and ashore information

users and providers much like commercial Internet services provide households and businesses today.

The bandwidth available via the Teledesic Commercial Wideband Satellite Communications System will support multiple-line telephone connectivity for official and crewmember use, video teleconferencing, video teleconferencing for remote training. It will also support video-telemedicine, medical imagery transmission, tactical and public affairs imagery transmission, national intelligence data base connectivity, and logistics. Teledesic provides the necessary connectivity to support all of these services simultaneously as well as many other high data rate services.

Teledesic can bridge the gap in high data rate communications until military wideband satellite communications systems can provide sufficient throughput to meet the warfighter's requirements. Once future requirements are met through enhanced MILSATCOM systems, the Teledesic system can provide an on-demand surge capability during contingency operations. High data rate duplex systems such as military or commercial wideband satellite communications can then be used for virtual theater injection by bringing high data rate information such as tactical imagery back to regional terrestrial networks.

With its high data rate and planned Internet quality video output, the Teledesic system would make an extremely effective command and control network. The system could provide direct videoconferencing from Battle Group Commanders to the CINC's. Through video patches from an unmanned vehicle, it could provide over-the-horizon targeting for cruise missile or the rail-gun. In coordination with UAV videolinks Teledesic could provide real-time battle damage assessment to allow air component and battlefield commander feedback for possible re-attacks. The commanders and ground troops on the front line, through the use of a laptop computer could relay real time situational reports for coordinated Battlespace awareness.

An increase in throughput or bandwidth has major effects on the supporting terrestrial infrastructure. Along with an increase in satellite communications capacity, a commensurate increase in terrestrial connectivity must occur in order for information to flow easily between afloat and ashore information providers and users. The introduction of the Teledesic System and other high data rate programs will greatly impact the terrestrial communications architecture. However, through programs such as DISN, Information Technology for the 21st Century, Base Level Information Infrastructure and the Automatic Digital Network System,

greater and more efficient terrestrial connectivity can be used to connect afloat and ashore information providers and users.

The CSCI study performed by three industry teams and managed by DISA determined that the most cost-effective use of commercial satellites occurs with little or no modification to the services provided or the terminals used. DoD should be able to inexpensively install or modify the Teledesic commercial satellite terminals for use on DoD platforms. The Teledesic commercial satellite system offers extensive value-added for DoD operations. Increased throughputs, additional types of services, freeing up MILSATOM bandwidth for protected service requirements, MWR services, and redundancy services are a few such value-added services. These value-added services offered by Teledesic provide DoD with better flexibility, improved warfighting capabilities in a Joint environment, cost-effective throughputs, and increased morale. Teledesic complements and augments specific MILSATCOM services and can be integrated into the MILSATCOM architecture. (Ref. 13: p. 5-41)

V. MILITARY CONCERNS WITH USING TELEDESIC AND POSSIBLE SOLUTIONS

A. MILITARY CONCERNS

In December of 1997 a Commercial Integrated Product Team (IPT) met with the purpose of conducting an end-to-end (terminal, ground, and space segment) evaluation of military and wideband commercial satellite communication requirements and systems. The IPT was to determine the right mix of commercial and military satellite services, the overall best acquisition strategy to acquire these services, and finally, acquire commercial satellite communications services as directed by CNO N6. (Ref 39: p. 1)

Among the issues to be studied during the IPT were commercial systems security, capacity, coverage, availability, and cost. At the time both the Teledesic and Celestri Wideband LEO communication systems were being studied. Since the IPT last met, these two systems have joined efforts and are currently being developed as the Teledesic system. The following paragraphs show possible solutions to concerns about using the Teledesic Wideband Communications System for DoD use.

1. SATCOM Security

Some warfighting networks must have the guaranteed protection and assured delivery of a MILSATCOM system, but in a low-jamming environment confronting a technologically inferior adversary even these requirements can be delivered using commercial wideband services. With the use of cryptographic equipment among U.S. and Allied forces and the lack of technological capability on the part of potential third-world enemies to design and build sophisticated jamming and detection systems, a portion of Navy SATCOM requirements have application to the Teledesic commercial satellite service. Teledesic can provide the basic requirements of data rate, coverage, and power.

The principal reason for using MILSATCOM to satisfy certain high value requirements is to provide assurance for a specialized set of capabilities that most commercial satellite systems are not designed to provide. These protection attributes include: (Ref. 13: p.5-12)

- Anti-jam (AJ)
- Low Probability of Intercept/Detection (LPI/LPD)
- Anti-Scintillation (AS)
- High Altitude Electromagnetic Pulse (HEMP)

Commercial wideband satellite systems may provide some of these capabilities unintentionally due to a particular system design or configuration, but certain designs may increase the vulnerability to various forms of electronic warfare (EW). Commercial wideband satellite systems have not been designed to provide protected transmission other than simple frequency reuse and spacing to prevent electromagnetic interference (EMI) between commercial satellite users and with terrestrial systems. Some commercial satellite designs may provide some limited degree of protection because of the access methods used, but such properties are usually circumstantial. Commercial satellite providers do protect the command links (Telemetry, Tracking, and Control) with the spacecraft to prevent unauthorized control to the spacecraft. Bulk encryption techniques may be employed by users of commercial satellite systems to provide COMSEC protection. Navy SATCOM requirements that do not need a set of extensive protection attributes are candidates for the Teledesic satellite system. (Ref. 13: p. 5-44)

SATCOM requirements can be assigned to MILSATCOM or commercial wideband satellite systems based on the type of protection required (if any) for the circuit. The assignment of a SATCOM requirement to a MILSATCOM or commercial satellite wideband system is dependant on the criticality of

the information, the survivability required of the circuit in accomplishing a particular mission, and the availability of satellite resources.

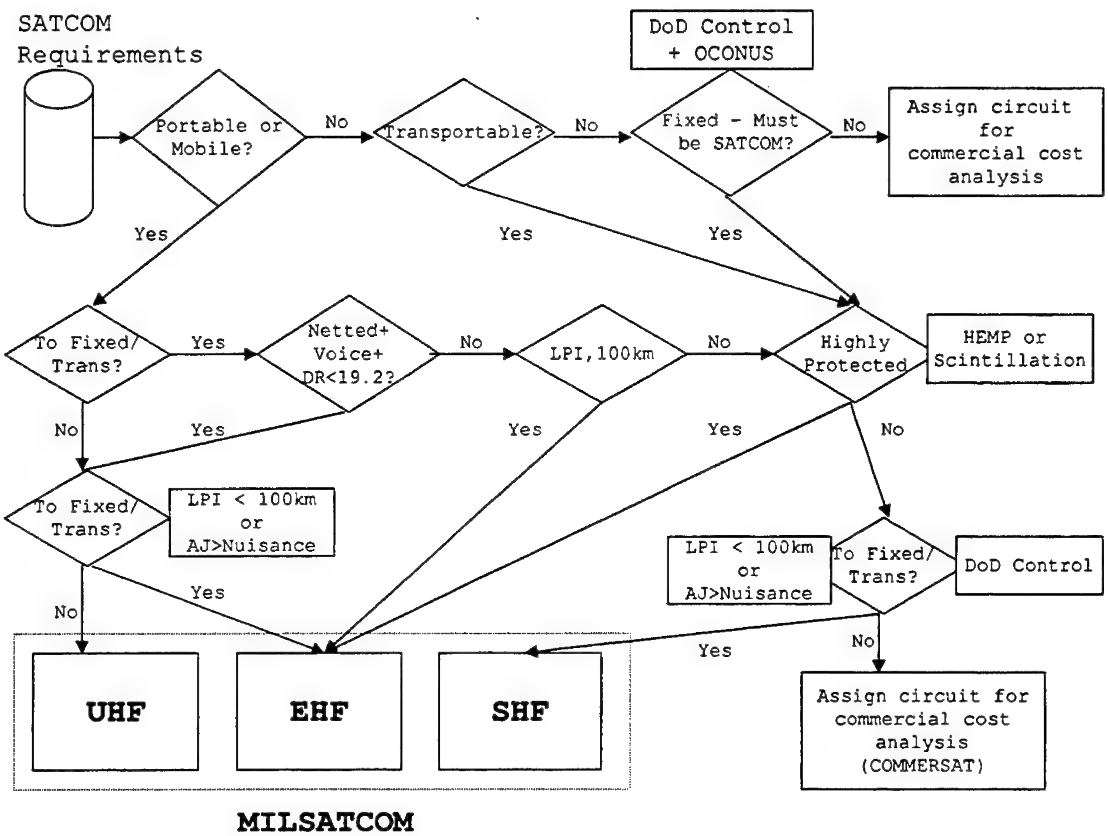

Figure 5-1, Basic Algorithm for Allocation. From Ref. [13].

The basic algorithm used by DISA to allocate SATCOM circuit requirements to the appropriate SATCOM system is shown in Figure 5-1. This algorithm was used to allocate the Navy SATCOM circuits in current communication system and emerging communication systems to either MILSATCOM or

commercial satellite systems, based on a Major Regional Conflict (MRC) scenario against a foe of limited technical means to jam or intercept SATCOM transmissions. Note that this algorithm will require modification when Teledesic becomes operational.

MILSATCOM:	**MILSATCOM or COMMERSAT:**	**COMMERSAT:**
AAW/ASW/ASUW C&R Nets	BF/BG FOTC Broadcast	BF/BG Ops/Admin
C2&Tac War Secure Voice	BGIXS	POTS
BF/BG Cmd and Tac Nets	CUDIXS	PRESS
C2W C&R	DMS Ship-Shor	NIPERNET
CTAPS	DSNET	SALTS
DAMA/Navy Orderwire	FLTBCST/HSFB	Secure Telphone
Dual ANDVT	FIST	TESS(3)
Joint Air Coordination	JDISS - GENSER & SI	VVFDT
Joint Command	JSIPS - NIS	*AIMD VTC*
JMCIS	JWICS	*Aircraft Maintenance Imagery*
Low-speed Tactical	SIPRNET	*ASVT*
MAGTF Nets	SSIX	*DSCS Emerg. Comm. Restoral*
MARCEMP	TDDS	*FLTGTADIXS*
NKMS	TACINTEL	*Multi-Purpose Marine Video*
NOW	VIXS	*N-ISDN*
OTCIXS		*N-ISDN*
SATHICOM		*Navy Logistics*
Special & Tailored Tac		*Public Affairs VTC*
TADIXS - A & B		*Quality of Life(MWR)*
Theater Unique		*Sailor Phone*
TIBS		*Telemedicine/Medical Imagery*
WWMCCS/GCCS		*Tomahawk*
FLTCTADIXS		*UAV Imagery*
ITVIXS		
S-TADIL		
SHF DAMA		

Table 5-1, Allocation of SATCOM Circuits. From Ref. [13].

Table 5-1 apportions the Navy SATCOM requirements into three categories. The first category is those basic C4I

circuits critical to tactical and strategic decision making. The successful coordination of these operations in a Joint operation environment typically must have the protection abilities afforded by MILSATCOM. The second category is operational and tactical circuits that may or may not require protection from jamming and LPI/LPD capabilities. The protection required is conditional based on the technical capabilities of the foe, the loading factor of MILSATCOM assets in the theater, and the assigned mission of the units. The CINC will allocate the circuits in this category to MILSATCOM or commercial satellite systems based on a prioritization of the circuits given the current mission(s) and tactical environment. As the mission(s) and tactical conditions change, the circuits can be reallocated to meet new operational security requirements. Depending on the mission and tactical environment, these circuits would benefit from greater bandwidths available on the Teledesic commercial wideband satellite system. The allocation of circuits to Teledesic would reserve MILSATCOM bandwidth for higher priority circuits. The third category circuits are generally voice or support circuits that will typically be allocated to commercial satellite systems and would be naturals to be placed on the Teledesic system. Emerging SATCOM requirements (listed in the table in italics) give a

sense of the growth of SATCOM circuit requirements in the future.

Depending upon the scenario and the threat, many of the circuits marked as candidates for commercial may use MILSATCOM or commercial satellite systems. The categorization of the SATCOM circuits is highly dependent upon the capabilities of the enemy and the mission. The currently planned orbiting capacity of MILSATCOM will not keep pace with the increase in capacity required by new services such as video and imagery, and the added demands for information to feed new sensors and weaponry. As the demand for SATCOM bandwidth increases (by the year 2010 Joint peacetime requirements are expected to increase 400 percent and wartime requirements by 500 percent over 1995 levels), the probable method for allocating circuits will be to assign MILSATCOM-only circuits to protected systems first. The remaining circuits will be allocated to MILSATCOM systems (providing some minimal protection capability) and/or commercial satellite systems based more on secondary attributes such as data rates and required coverage rather than protection requirements. (Ref. 13: p. 5-15)

2. Teledesic Network Security

Features in the Teledesic system design provide some degree of protection and Low Probability of Intercept (LPI) from intruders on the network. These protection features would be of added benefit to DoD users. The Teledesic Management System controls the configuration of the network, network routing and levels of service allocated to a user. This is done by loading software into the satellites and satellite-terrestrial interfaces, and setting the operational parameters for that software. This is an administrative process whereby communications with the nodes in the satellite and satellite-terrestrial use a secure, encrypted communications protocol. The uplink is particularly sensitive to attempts to make unauthorized use of the networks resources. Among a range of facilities to control this are: (Ref. 40)

1. The Teledesic interface devices monitor all Bandwidth-on-Demand (BOD) messages to a cell that allocate bandwidth and de-allocate it. Any message that is not consistent with the state of Teledesic interface devices is reported to the Teledesic Management System. This feature will act as an alert to any intruder trying to uplink on the network.

2. Unallocated uplink capacity is blocked in the satellite.

3. The Teledesic Management System can instigate, at random, a request for the Teledesic interface device that is using a particular uplink time slot to identify itself and provide its latest traffic statistics. This process is acknowledged by the Teledesic Management System: any Teledesic interface device seeing a surprise acknowledgement message (an ACK received for a data packet that it did not send) reports the event.

4. The traffic collection processes are such that the Teledesic Management System may determine whether or not the uplink capacity used in a given period corresponds to the usage reported by all the authorized Teledesic Interface devices in that cell.

5. The BOD requests from a specific cell may be accumulated and transmitted to a monitoring terminal on the ground. In addition, within a cell it is possible to install a terminal that monitors all BOD commands to the Teledesic interface devices in that cell.

6. Because of the steep angle of the uplink beams, interception of these encrypted signals would prove difficult to an enemy. Also the process of switching information packet routing within the network could be used to decrease susceptibility to jamming.

7. The Teledesic System will encrypt the data packets within its system. The ADNS system will also add an encryption layer to the data packets ADNS using a Network Encryption Device (NED). DoD encryption devices could first encrypt these packets. This would cause an adversary to peal through three layers of encryption to retrieve any data that was intercepted. This will secure the data, without the need to secure the data pipe.

The ability, on a selective basis, to monitor the details of the network activities is provided to assist the network operator diagnosing problems, studying customer complaints and looking for unauthorized activities.

3. Capacity

Capacity is seldom quarantined on commercial satellite systems unless a transponder is leased for long periods of time or a First Right of Refusal (FRR) is placed on the bandwidth. An FRR allows the holder to reserve bandwidth with a service provider. Should the service provider have a

second customer for the reserved bandwidth, the FRR holder has the right to lease the bandwidth first or give up the bandwidth to the second customer. This system of first-come, first served would require DoD to exercise a FRR prior to a contingency or a period of heavy usage in order to maintain the rights to the bandwidth. This type of arrangement would incur additional cost, but constitutes a cost-of-doing-business within the commercial sector. (Ref. 13: p. 5-44)

4. Coverage

Coverage is another important limitation with commercial satellite systems. Lack of coverage of a particular operating area with sufficient power can severely limit the throughput achievable on commercial satellite systems. Commercial satellite systems primarily focus their coverage on regions with high-traffic demand. Coverage to other areas is usually at lower power levels and requires larger antennas to achieve the same throughputs achievable at the beam center. In the operating areas in which the Navy is frequently tasked, coverage from Ku-band spot beams is generally non-existent. C-band hemisphere and zone antennas are generally available in most littoral areas, but coverage to the central ocean areas is usually available only on low powered global beams. With the Teledesic System still under development DoD needs to influence the development process

early. If it doesn't Teledesic may develop a system that uses the open ocean areas and less populated regions of the world to conduct satellite housekeeping functions, such as battery recharging and satellite repositioning. This would deny system use to regions in which the DoD operates. An early fiscal investment and exchange of research and development ideas could facilitate DoD influence on the Teledesic system development. The Teledesic commercial wideband satellite system may or may not offer the flexibility DoD Navy has with MILSATCOM, but many service providers are willing to provide flexibility to customers for a price. Pre-negotiated leases and services will reduce the cost factor.

5. Availability

Availability and Cost are key factors to consider in using commercial wideband satellite systems. During times of crises DoD will be competing with a variety of commercial interests as well as commercial news organizations, such as CNN, for limited amounts of bandwidth in a particular region. The demands for limited bandwidth will likely drive up the costs unless prearranged lease prices and options are available. With the first-come, first-served nature of commercial satellite systems, it is not enough to have pre-

arranged lease prices, availability may be the issue. The DoD must act quickly to put leases in place on bandwidth in the wideband area, which may require leasing bandwidth prior to actually being able to use it.

Once the bandwidth is leased the issue of throughput becomes a concern. How will DoD ensure that its data packets arrive at their destination in a timely manner? The Teledesic system has several options available to ensure that priority data is received when it is needed.

The Bandwidth On Demand software (BOD) will monitor requests from one of 4 network addresses that are defined by the Teledesic Management System, and copy these requests to the administrative software for accumulation and transmission to the Teledesic Management System. (Ref. 40)

Type 1: P1 priority

Reserved capacity on uplink, downlink and all inter-satellite links over which the Teledesic data Packets may travel. The P1 routing tables are set to give minimal hop path and alternate paths. The difference in the number of hops taken by any two Teledesic Data Packets will be less than four.

Type 2: P2 priority

Reserved uplink and downlink capacity and inter-satellite links but with a statistical component. P2 routing tables set to minimize conflicts with P1 where possible, and number of hops minimal within this constraint. The difference in hops taken by any two Teledesic data Packets will be less than four.

Type 3:P3 priority

Reserved uplink and downlink capacity. The reservations may be for aggregated traffic with a statistical component, and some degree of over-subscription is possible. Over-subscription on the gigabit inter-satellite links will provide considerable opportunity for maximizing the billable Bandwidth. P3 routing tables set to avoid major traffic sources and heavily reserved links. A dynamic routing program may modify tables. Delay is only bounded by time out period for all Teledesic Data Packets.

Type 4:P4 priority

No reservations made and only uplink bandwidth allocations are available, for potentially limited periods of time. P4 tables set up is done similarly to P3 and an independent dynamic routing program updates entries.

Within satellite-terrestrial interface and Teledesic service applications a suite of test software may be activated to permit detailed monitoring of data flow on a per link across the network or destination node address. A Teledesic interface device may transmit all Teledesic Data Packets received to a monitoring Teledesic service application as well as the intended destination node. With this system the DoD will be able to monitor its traffic flow and prioritize its data in accordance with increasing threat conditions. (Ref. 40)

6. Cost Analysis

Satellite bandwidth or access time must be leased once the DoD has identified the Teledesic system to satisfy specific commercial wideband satellite services. For Fixed Satellite Systems (FSS) and Broadcast Satellite Systems (BSS), the service providers charge the user based on the amount of transponder bandwidth or power used whichever is higher. The charges are based on tariffs filed with their respective regulatory agency. In the U.S. tariffs are filed with the FCC. However, not all satellite service providers are required to file tariffs. Comsat must file tariffs with the FCC by virtue of their regulated monopoly on U.S. users of the INTELSAT system. Orion Atlantic L.P. and PanAmSat

Corp., however, do not have structured rates for the use of their satellite systems. Users negotiate prices with these providers based on the amount of bandwidth/power, the length of the contract, and the current market prices for similar services. (Ref. 13: p. 5-50)

Mobile Satellite Systems (MSS) systems charge the users based on the type of service employed and the number of minutes or data packets sent. In addition to the satellite space segment, the user may also be responsible for terrestrial long-distance charges from the gateway accessed. The Inmarsat space segment charge includes the cost of the terrestrial link back to Inmarsat gateway in the destination country. Users are only responsible for any terrestrial long-distance charges from the gateway to the call's final destination. The planned MSS systems have not indicated in public literature what portion of the terrestrial charges, if any will be included with the space segment cost. One indicator that terrestrial charges will not be included is the fact that most of the foreign partners in these systems are equipment manufacturers and not terrestrial service providers. Unless these MSS systems conclude negotiations with terrestrial service providers in each country with a gateway, the user will more than likely be responsible for paying the terrestrial service charges. For calls placed

from one terminal to another terminal, space segment charges are incurred for each terminal. (Ref. 13: p. 5-50)

Because of its on-board processing and crosslink design, Teledesic permits a circuit to downlink directly from one terminal to another without having to always use terrestrial gateways. The Teledesic system may have to use a combination of FSS and MSS billing methods; MSS billing methods for mobile units, ships and aircraft, and FSS methods for gateways at the NOCs.

One method to reduce the cost per MHz of bandwidth for wideband duplex operations is to lease the largest amount of bandwidth possible. The DoD can accomplish this by bundling all circuit requirements in a region on one transponder. In addition to DoD circuit requirements, circuit requirements from other Government agencies can be included to add to the total requirement. As the amount of bandwidth required increases, the cost of the bandwidth on a per MHz (or dB for power) basis decreases. After negotiating for the total bandwidth required from Teledesic, each circuit would be allocated a specific amount of the overall bandwidth. Each service or Government agency would be responsible for establishing and maintaining its own circuit; however, each would benefit form the cost-savings received for bundling the requirements together.

One contract vehicle available to the DoD to lease FSS bandwidth is the DISA-managed "Transponder Leases and Bandwidth Management" contract (also referred to as the CSCI Follow On contract). This contract provides for DISA to lease from 2 to 45 whole transponders on a global basis. The contract length is 1 year with nine 1-year options. DoD may lease a whole transponder for internal use or, should a requirement exist for only a partial transponder, submit the partial transponder requirement to DISA to determine if another government agency has a similar requirement for FSS service. DISA could then bundle the two requirements and justify the cost of leasing a whole transponder. Should no other similar requirement exist to bundle with the DoD's requirement, the DoD will have to use a different contract vehicle because the Transponder Leases and Bandwidth Management contract does not provide for leasing partial transponders. (Ref. 13: p. 5-51)

Related to bundling circuit requirements together is the length of the lease term. In general, commercial service providers will offer reduced rates for the longer-term contracts. Short-term (less than one year) contracts typically cost most. By leasing bandwidth over a longer period it is possible to acquire 3 to 5 times the bandwidth for the same price as a short-term lease. Should the

bandwidth not be in use by the mobile terminals, DoD shore installations such as NOCs with gateways could use the bandwidth to augment the current DSCS MILSATCOM system. These new hub stations can also serve as regional ADNS/Defense Information System Network (DISN) gateways.

If the Teledesic system charges on a per minute or per data packet basis, the DoD should use the same acquisition process currently in place for leasing Inmarsat space segment. Significant savings can be achieved by leasing through prior agreements of bulk network time on the system. Additional savings can be received by developing these relations with the proposed Teledesic system prior to their launch. By entering agreements with Teledesic, the DoD will incur some risk that the system may be launched behind schedule. However, in return for providing Teledesic with a base customer, the DoD can negotiate special prices and services from the provider that will not be available to other customers. Additionally, the DoD may consider negotiating for DoD owned and controlled gateways to the Teledesic system (similar to Iridium) or for special permission to connect ADNS/DISN links to commercially operated gateways. This can reduce terrestrial long-distance charges as compared with using commercial landlines. Additional considerations should be given for installation

of hub satellite stations/gateways on foreign soil as the costs of tariffs will drive up the operating costs, and permission or granting authority to use such installations is an extremely slow administrative process.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Present day acquisition focuses heavily on procurement of intelligence gathering and production systems as well as sophisticated weapons platforms and munitions: to a much lesser extent on the communication links to support these elements. However, modern warfighting intelligence and weapons systems require a vast transmission capacity to support them. Command, Control, Computer, Communications and Intelligence (C4I) systems are force multipliers which allow smaller, better equipped warfighting forces to be more effective. In this era of right-sizing, force multipliers, like C4I systems, and mainline commercial technologies have become increasingly important to mission success.

Although large volumes of intelligence information are available to warfighting CINCs, today's MILSATCOM system has insufficient capacity to transmit this information, in timely fashion, from national collection and processing facilities to JTF and deployed forces. Requirements growth has historically outpaced satellite communications capabilities, and the shortfall is becoming greater every year.

One solution to this intelligence transmission shortfall is the Teledesic Commercial Wideband Satellite System which has the potential to fulfill many of DoD SATCOM requirements. The Teledesic system is characterized by a wide variety of services, capabilities, and cost allowing flexibility for DoD procurement. Once a SATCOM requirement has been designated as a candidate for commercial satellite, the required attributes of data rate, power, and coverage of a DoD SATCOM requirement can become the focus for matching up with the Teledesic system. The Teledesic system will provide DoD with higher power transponders, new frequencies, and enhancements in antenna technology that may extend the reach of wideband duplex services to smaller platforms such as cruisers, destroyers, and platoon size units.

The integration of Teledesic into the MILSATCOM satellite architecture will enable DoD to meet some of its goals in programs such as Joint Vision 2010 and IT-21. Teledesic could provide the networking for DoD Internet functions such as email and the World Wide Web as well as transport for tactical and non-tactical data. Teledesic will provide a full duplex system for "user pull" of information. The Teledesic system's low latency will allow it to use standard Internet protocols for ease of systems integration

and the use of off-of-the shelf applications, all goals of JV 2010 and IT-21.

The JMCOMS's, ADNS and ITP programs will allow for easy integration of the Teledesic system into the DoD networking architecture. Through use of the Teledesic system, JMCOMS networks can interface through Standardized Tactical Entry Points (STEP) to the packet data networks of the other services to include the Army's "Enterprise" Network and the Air Forces' "Horizon" Network. With an Automated Digital Network System (ADNS) Channel Access Protocol (CAP), Teledesic will interface with the SIPRNet/NIPERNet through the evolving shore communications infrastructure. JMCOMS addresses both technical and implementation challenges of integrating Teledesic with a clear strategy. Rapid advances in telecommunications technology and products is key. Many off-the-shelf products for routing, addressing, networking and network management are available and compatible with the Teledesic system. DoD should be able to inexpensively install or modify the Teledesic commercial satellite terminals for use on DoD platforms.

The Teledesic commercial satellite system offers extensive value-added for DoD operations. Increased throughputs, additional types of services, freeing up MILSATCOM bandwidth for protected service requirements, MWR

services, and redundancy services are a few such value-added services. These value-added services offered by Teledesic provide DoD with better flexibility, improved warfighting capabilities in a Joint environment, cost-effective throughputs, and increased morale. Teledesic complements and augments specific MILSATCOM services and can be integrated into the MILSATCOM architecture.

With its high data rate and planned Internet quality video output, the Teledesic system would make a very effective command and control network. The system could provide direct videoconferencing from Battle Group Commanders to the CINC's. Through video patches from an unmanned vehicle, it could provide over-the-horizon targeting for cruise missiles or the rail-gun. In coordination with UAV videolinks, Teledesic could provide real-time battle damage assessment to allow air component and battlefield commander feedback for possible re-attacks. The commanders and ground troops on the front line, through the use of laptop computers could relay real time situational reports for coordinated Battlespace awareness.

Teledesic can bridge the gap in high data rate communications until military wideband satellite communications systems can provide sufficient throughput to meet the warfighter's requirements. Once future requirements

are met through enhanced MILSATCOM systems, the Teledesic system can provide an on-demand surge capability during contingency operations. High data rate duplex systems such as military or commercial wideband satellite communications can then be used for virtual theater injection by bringing high data rate information such as tactical imagery back to regional terrestrial networks.

The Teledesic system offers a high degree of information security and capacity. Depending on the future acquisition strategies of DoD toward Teledesic, coverage and availability could be assured at a reasonable cost.

The currently planned orbiting capacity of MILSATCOM will not keep pace with the increase in capacity required by new services such as video and imagery, and the added demands for information to feed new sensors and weaponry. As the demand for SATCOM bandwidth increases, the probable method for allocating circuits will be to assign MILSATCOM-only circuits to protected systems first, as in the DISA algorithm. The remaining circuits will be allocated to commercial SATCOM systems. Teledesic should be one of the commercial systems used.

B. RECOMMENDATIONS

In December 1997, both the Commercial Wideband Integrated Product Team for the Chief of Naval Operations and the MITRE corporation satellite systems assessment team were giving and receiving briefs to/from senior officers in the C4 and IW communities. The prevailing attitude toward the Teledesic system as well as other commercial wideband systems was "wait and see". They recommended waiting to see what commercial satellite systems did and whether they developed to meet military requirements. This was to be done without any investment into the commercial wideband systems in the hope that the commercial systems would just naturally develop into a system that could be used by DoD without any up-front investment. This may be a good acquisition strategy, but it doesn't seem to be a sound development strategy. (Ref. 41)

Commercial satellite systems are not represented by a single technology or design, but rather are defined by the market requirements they are designed to fulfill. If DoD does not identify itself as a potential market to the Teledesic system, the system may develop away from DoD requirements. The availability of Teledesic wideband services to the central ocean regions or sparsely populated areas of the world is unlikely, due to a lack of commercial

market for this type of service, unless DoD invests in the development process. Otherwise, Teledesic architectural design may call for these areas of possible coverage to be used only for satellite health and welfare operations. If the DoD is not part of the systems development process, they will find that the Teledesic system is on-line and will not be able to functionally change to meet DoD requirements. DoD will have ever increasing bandwidth demand without a MILSATCOM architecture to meet those demands. They will find that they are left with an increasing number of requirements unfulfilled and no means to alleviate the pressure of meeting the warfighters and weapons needs. It is recommended that DoD approach Teledesic early in the systems development process and establish itself as a preferred customer, with an up-front investment to influence the systems requirements process.

The Office of Naval Research (ONR), SPAWAR's Advanced Technology Directorate, the Naval Research Laboratory and other Service laboratories are pursuing advanced antenna and radio frequency component technologies which will contribute to the future evolution of Integrated Transponder Program systems. DoD is conducting RDT&E efforts in multifunction and multiband apertures (under the Multibeam Multifunction Broadband Antenna project), advanced RF waveforms, solid

state amplification, programmable modems and potential for phased array technology. The system designers of Teledesic are addressing similar issues and conducting the same research. If DoD decided to use the Teledesic system, research efforts should be coordinated to avoid duplication of effort and thus create a development cost savings. DoD could then have some influence on antenna design features for its platforms.

Commercial organizations receive better pricing by ordering bandwidth on satellites prior to their launch. By communicating their requirements to the satellite service providers well in advance, the service providers will modify the coverage patterns, power outputs, and transponder layouts of future spacecraft to meet a customer's specific requirements, in return for long-term lease agreements. DoD should communicate their current and future commercial satellite requirements to Teledesic regularly, so that the requirements will be considered in the design of future commercial spacecraft. While there is risk involved in leasing transponder service prior to the satellite's launch, due to launch failures, the overall savings incurred over a 5 or 10-year pre-launch lease can far outstrip the loss from launch failure.

Another recommendation to reduce the cost per MHz of bandwidth for wideband duplex operations is to lease the largest amount of bandwidth possible. It is recommended that the DoD accomplish this by bundling all circuit requirements in a region on one transponder. In addition to DoD circuit requirements, circuit requirements from other Government agencies can be included, adding to the total requirement. As the amount of bandwidth required increases, the cost of the bandwidth on a per MHz (or dBW for power) basis decreases. After negotiating for the total bandwidth required from Teledesic, each circuit would be allocated a specific amount of the overall bandwidth. Each service or Government agency would be responsible for establishing and maintaining its own circuit; however, each would benefit form the cost-savings received for bundling the requirements together.

The final recommendation related to bundling circuit requirements is the length of the lease term. In general, commercial service providers will offer reduced rates for the longer-term contracts. Short-term (less than one year) contracts typically cost most. It is recommended that DoD lease bandwidth over a longer period. It is possible to acquire 3 to 5 times the bandwidth for the same price as a short-term lease. When the bandwidth is not being used by

the mobile terminals, DoD shore installations such as NOCs with gateways could use the bandwidth to augment the current DSCS MILSATCOM system. These new hub stations can also serve as regional ADNS/Defense Information System Network (DISN) gateways.

APPENDIX

ACRONYMS

AAW	Anti-air Warfare
ADNS	Automated Digital Network System
AICS	Automated Integrated Communication System
AJ	Anti-Jam
AOO	Area of Operations
AOR	Area of Responsibility
ANX	Automotive Network Exchange
AS	Anti-Scintillation
ATDMA	Asynchronous Time Division Multiplexing Access
ATM	Asynchronous Transfer Mode
AUTODIN	Automatic Digital Network
BDA	Battle Damage Assessment
BOD	Bandwidth On Demand
CAP	Channel Access Protocols
CEC	Co-operative Engagement Concept
CJCS	Chairman of the Joint Chiefs of Staff
CNO	Chief of Naval Operations
COE	Common Operating Environment
COTS	Commercial Off-the-shelf
CRIU	Channel Access Protocol Router Interface Unit
CSCI	Commercial Satellite Communications Initiative
CSOM	Communications System Operations Manager
DII	Defense Information Infrastructure
DISA	Defense Information Systems Agency's
DMS	Defense Messaging System
DoD	Department of Defense
DSCS	Defense Satellite Communications System
EHF	Extra High Frequency
EIRP	Equivalent Isotopic Radiated Power
ELINT	Electronic Intelligence
ERDB	Emerging Requirements DataBase
FCC	Federal Communications Commission
FLTSATCOM	Fleet Satellite Communications
FRR	First Right of Refusal
FSS	Fixed Satellite Service
GBS	Global Broadcast System
GCCS-M	Global Command Control System - Maritime
GEO	Geostationary Earth Orbit
GOTS	Government Off-the-shelf

HAEP	High Altitude Electromagnetic Pulse
HF	High Frequency
ICDB	Integrated Communications DataBase
IP	Internet Protocol
IPT	Integrated Product Team
INM	Integrated Network Management
IR	Infa-red
ISDN	Integrated Services Digital Network
ISL	Inter-satellite Link
ISP	Internet Service Provider
IT-21	Information Technology for the 21st Century
ITP	Integrated Terminal Program
JBS	Joint Broadcast System
JMCOMS	Joint Maritime Communications Strategy
JMCIS	Joint Maritime Communications Information System
JROC	Joint Requirements Oversight Council
JSCP	Joint Strategic Capabilities Plan
JSMB	Joint Space Management Board
JSP	Joint SATCOM Panel
JSPA	Joint SATCOM Panel Administrator
JTA	Joint Technical Architecture
JTF	Joint Task Force
JV-2010	Joint Vision 2010
LAN	Local Area Network
LEO	Low Earth Orbit
LOC	Local Operations Center
LOICE	Link Operations Intelligence Center-Europe
LOS	Line of Sight
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
MAA	Mission Area Analysis
MF-TDMA	Multi-Frequency Time Division Multiple Access
MILSATCOM	Military Satellite Communications
MSS	Mobil Satellite Service
MTW	Main Theater of War
NATO	North Atlantic Treaty Organization
NIPERNET	Non-Secure Internet Protocol Router Network
NMA	Network Management Architecture
NOC	Network Operations Center
OPLAN	Operations Plan
OPORD	Operations Order
PDS	Packet Data Subsystem

POP	Point of Presence
PPBS	Planning Programming and Budgeting System
PSK	Phase Shift Keying
PTSN	Portable Telephone Satellite Network
QOS	Quality of Service
QPSK	Quadrature Phase Shift Keying
ROC	Regional Operations Center
SATCOM	Satellite Communications
SDI	Strategic Defense Initiative
SHF	Super High Frequency
SIPERNET	Secret Internet Protocol Router Network
SLEP	Satellite Life Extension Program
SNMP	Simple Network Management Protocols
Swarf	Senior Warfighters' Forum
TBMD	Theater Ballistic Missile Defense
TCP	Transmission Control Protocal
TDMA	Time Division Multiple Access
UFO	UHF Follow-on
UHF	Ultra High Frequency
USSOCCOM	United States Special Operations Command
WAN	Wide Area Network

LIST OF REFERENCES

1. Munro, Neil, "Industry Boosts DoD Gulf Communications," *Defense News,* 19 November 1990.

2. "Crisis Shows Need For Better Tactical Satellite Communications," Aerospace Daily, 31 January 1991.

3. Brewin,Bob, "Bosnian Mission Demands most Complex Network Ever," *Special Report: Bosnia*, 29 April 1996.

4. Brewin, Bob, "Bosnia support nets to get upgrade," *Special Report: Bosnia,* 5 February 1996.

5. Department of Defense, *Advanced Military Satellite Communications Capstone Requirements Document,* 24 April 1998.

6. Department of Defense, *Introduction to Defense Acquisition Management* (Second Edition), Defense Systems Management College Press, March 1993.

7. Chairman of the Joint Chiefs of Staff, *Memorandum of Policy No.37,* Military Satellite Communications Systems, 14 May 1992.

8. Chairman of the Joint Chiefs of Staff, Satellite Communications (Instruction Draft), CJCSI 6250.01, 31 August 1998.

9. Joint MILSATCOM Panel (JMP), *EMERGING REQUIREMENTS DATA BASE, Joint MILSATCOM Panel (JMP) REVIEW, Command Briefings,* Meeting Minutes, 11-14 February 1997.

10. Mayo, Dick, RADM., (CNO N60), *IT21 Presentation to Naval Postgraduate School*, August 1998.

11. Commander, *Naval Space Command, Naval SATCOM Emerging Requirements Data Base*, Version 4.0, 1 May 1997.

12. Finnegan, Mike, Lt., USN, SATCOM Plans and Policy (N521), *ICDB/MOP-37/ERDB Requirements Process*, October 1997.

13. Commander, Naval Space Command, N52, *Commercial Satellite Communications (SATCOM) Satisfying Naval Requirements,* August 1996.

14. Commander, Naval Space Command, *Naval Satellite Communications Functional Requirements Document*, 25 February 1997.

15. Hedges, Cliff, SEMCOR, Inc., *Future MILSATCOM Architecture*, Space Systems 4900 (MILSTACOM) lecture for Naval Postgraduate School, November 1997.

16. Moneymaker, Patrick D., Rear Adm., "Joint Investment in a Joint Medium", *Naval Space Command SPACE TRACKS,* May/June 1998.

17. Hampton, Phil, SEMCOR, Inc., *Commercial Wideband,* Space Systems 4900 (MILSTACOM) lecture for Naval Postgraduate School, November 1997.

18. Hampton, Phil, SEMCOR, Inc., *Emerging Commercial SATCOM in the Navy*, Space Systems 4000 (Space Systems Seminar) lecture for Naval Postgraduate School, 11 September 1997.

19. Brandt, Richard. *Interview with Teledesic President Russell,* www.upside.com/teledesicarticle.html

20. Federal Communications Commission, Washington, D.C., *Application of Teledesic Corporation for Low Earth Orbit Satellite Sysytem in The Domestic and International Fixed Satellite Service*, 21 March 1994.

21. Hardy, Quentin, *Teledesic Corp., Boeing Strike a Deal On Satellite-Network Project, Investment,* (The Wall Street Journal), 30 April 1997.

22. Rountree, Kristen, "Teledesic, Motorola Join in Satellite Venture," *International Space Industry Report*, 8 June 1998.

23. Maney, Kevin, "Teledesic Moves Toward Space-Based Net", USA Today, 27 February 1998. www.teledesic.com/overview/usatoday2-27.html

24. Burke, Jonathan, "BIRD MAN - An interview with Russell Daggatt, president of Teledesic," The Herring Interview, March 1996. www.herring.com/mag/issue29/man.html

25. Teledesic Corp., "Latency White Paper", Teledesic Web Page, 1 December 1997. www.teledesic.com/tech/latency.html

26. Teledesic Corp., *Technical Overview of the Teledesic Network*, Teledesic Web Page, 1 December 1997. www.teledesic.com/tech/details.html

27. Gaffney, Leah M., *An Evaluation of the Spaceway and Teledesic Systems*, The MITRE Corporation, April 1995.

28. Crane, R. K., "Prediction of Attenuation by Rain," IEEE Transactions on Communications, Vol. COM-28, No. 9, September 1980.

29. Federal Communications Commission, Washington, D.C., *Amendment of Application of Teledesic Corporation to Construct, Launch, and Operate a Low Earth Orbit Satellite Sysytem in The Domestic and International Fixed Satellite Service*, 30 December 1994.

30. Cheshire, Stuart, *Latency and the Quest for Interactivity,* November 1996. ResComp.Standford.EDU/~cheshire/

31. Comer, Douglas E., *Computer Networks and Internets,* Pretice-Hall, Inc., 1997.

32. Kaminski, Paul J., *Statement of The Under Secretary of Defense for Acquisition and Technology Paul J. Kaminski before the House Appropriations Committee, National Security Subcommittee in Connection with the FY 1996-97 Department of Defense Space Activities,* 23 March 1995.

33. Trammell, John, N52, "Naval Tactical Interoperability - Implementing Information Technology for the 21st Century (IT-21)", *MILCOM 97 Panel,* 30 October 1997.

34. Commander, Naval Surface Forces U.S. Atlantic Fleet, "ADNS for Expeditionary Warfare", *Naval Expeditionary C4ISR Requirments Conference (NECC),* 22-25 April 1997. www.cnsl.spear.navy.mil/N6/N62/NECC/exco.htm

35. Department of Defense, "Automated Digital Network System", *Joint Maritime Communications System.* www.jmcoms.org/jmcoms/online/explained/moreadns1.htm

36. Naval Command Control and Ocean Surveillance Center Research, Development, Test and Evaluation Division (NRaD),Code 80, *Automated Integrated Communication System (AICS), Network Management Architecture for the Advanced Digital Network System (ADNS)*, 30 September 1996.

37. Department of Defense, "Joint Maritime Communications System, PMW 176-4 (Maritime Wideband RF Systems) Explained", *Joint Maritime Communications System.* www.jmcoms.org/jmcoms/online/programs/176-4 /explained/itpexplained.htm

38. Shaw, James J., LCDR., USN, "Naval Satellite Communications for the 21st Century", *1996 AIAA Space Programs and Technologies Conference*, 24-26 September 1996.

39. Chief of Naval Operations, N6, *CHARTER, Naval Integrated Product Team for Commercial,* December 1997.

40. Teledesic Cooperation, *The Teledesic Network.* This is a paper on the Teledesic Network provided to me by Gordon W. Booker, Government Services Consultant, for the Teledesic Cooperation.

41. MITRE Corporation, "Connectivity Issues - Status brief to C4 & IW JMA Assessment Working Group", *Communications in Support of Naval Force Operations in 21st Century*, 9 December 1997.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center..2
   8725 John J. Kingman Rd., STE 0944
   Ft. Belvoir, Virginia 22060-6218

2. Dudley Knox Library..2
   Naval Postgraduate School
   411 Dyer Road
   Monterey, California 93943-5101

3. Craig W. Baldwin (Code AA/Ba)..1
   Naval Postgraduate School
   Monterey, CA 93943-5002

4. Professor Donald v.Z. Wadsworth (Code EC/Wd)..1
   Naval Postgraduate School
   Monterey, CA 93943-5002

5. LCDR James O. Wickline...1
   Naval Space Command
   5280 Fourth St.
   Dahlgren, VA 22448-5300

6. John Trammell...1
   Naval Space Command
   5280 Fourth St.
   Dahlgren, VA 22448-5300

7. SATCOM Plans and Policy (N52)...1
   Naval Space Command
   5280 Fourth St.
   Dahlgren, VA 22448-5300

8. MILSATCOM Requirements Officer 1
   MCCDC
   Requirements Division C442
   3300 Russell Road
   Quantico, VA 22134-5021

9. Dr. Roy Axford...1
   Space and Naval Warfare Systems Center
   53560 Hull Street
   San Diego, CA 92152-5001

10. CDR D. Creasy 1
Asst for Commercial SATCOM (N631J)
Space, Information Warfare, Command and Control Directorate
Office of the Chief of Naval Operations
Presidential Towers (NC1)
Crystal City, Arlington, VA 22202

11. CDR D. A. Baciocco 1
MILSATCOM Programs Department of Defense Space Architect
2461 Eisenhower Avenue, Suite 164
Alexandria, VA 22331-0900

12. Marine Corps Tactical Systems Support Activity 1
Technical Advisory Branch
Attn: Maj J.C. Cummiskey
Box 555171
Camp Pendelton, CA 92055-5080

13. Gordon W. Booker 1
Government Service Consultant
Teledesic Corporation
Jefferson Davis Hwy, # 610
Arlington, VA 22202